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Essays on planning food processing industries

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Essays on planning in food processing industries

The case of a dairy factory

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RIJKSUNIVERSITEIT GRONINGEN

Essays on planning in food processing industries

The case of a dairy factory

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1. Introduction

My first impressions when I walked through the dairy factory of FrieslandCampina in Leeuwarden were overwhelming; such a large production site daily processing 2500 Tons of milk. A huge factory, in which the milk flows through an abundant number of pipes and numerous storage tanks in order to be pre-processed, processed and finally packed on more than 20 packaging lines. Moreover, a gigantic can factory was on the same site producing a billion cans yearly of which only a small amount can be stored due the capacity limitation of the intermediate warehouse. While I walked around, several questions popped up. How much does the delivery and consumption of milk fluctuate during the day? How many tanks are sufficient to buffer the milk? How are these consecutive production processes planned? What is the appropriate production strategy (Make-to-order or Make-to-stock) for the products? And how many cans need to be stocked to guarantee the smooth delivery of cans to the packaging stage?

Through the four years that I worked at the factory the fascination for the production process remained, where, together with my colleagues, I was able to find answers to some of the questions raised above. While studying the factory I found that the factory, which has been located at the same site for over 100 years, was not a static but a dynamic system. Market conditions fluctuate, management focus changes over time as well as the position of the factory within the company, all resulting in dynamic operating conditions. Below we provide a number of examples of these operating conditions. The demand for certain products occasionally rapidly increased particular for markets in third world countries. Contrary, during the financial crisis in 2008 the demand for many products drastically dropped. In some periods there was a strong management focus on the reduction of inventory levels whereas at other times large inventories were used to temporarily store a part of the surplus of milk within the company. Next to the overstocked warehouses due to the milk surplus, the opposite also occurred; in some periods there was not enough milk to satisfy all the customer demand resulting in strongly shrinking inventory levels throughout the supply chain.

The planning challenges the factory faces to deal with these dynamic operating conditions are not unique. Through the growing competition in the international markets, food processing companies have to adapt quickly to fast changing and unpredictable customer demand. By in-depth studying this particular company as a specific case we do not only aim to contribute to solutions for the planning challenges in this company, but to generate

insight on how to deal with similar planning issues in a wider range of food processing companies as well.

In the remainder of the chapter we therefore discuss the characteristics that are typical for the food processing industry and what is known on how these characteristics affect planning decisions. Subsequently we provide a description on the market and company dynamics that also affect planning decisions and pay attention to the different planning levels that can be identified within the case company. Finally, we selected the research aims of the thesis based on theoretical and managerial relevance.

1.1 Characteristics of the food processing industry

Taylor *et al.* (1981) showed that differences in marketing, manufacturing and financial environments cause different emphasis on production and inventory management between process industries and discrete manufacturing. Within the process industries also large differences are found (Fransoo and Rutten, 1994). Process industries vary from process/flow businesses (like oil and steel industries) to batch/mix businesses (like drugs and specialty chemicals) where ‘pure’ process industries are scarce. Many firms that consider themselves to be in the process industries are actually hybrids due to the fact that their products become discrete at a point during the manufacturing process (Dennis and Meredith, 2000).

Food processing industries tend to have less product differentiation than fabrication and assembly industries and therefore were traditionally producing in large batches to reduce setups and to keep production costs low. Over the last three decades this is shifting due to faster changing and less predictable consumer wishes, retailers restructuring the supply chain, and lower margins paid to producers. These changes cause the food processing industries to experience growing logistical demands, growing variety in products, and more intense competition (e.g. Van Donk, 2001). As a reaction, companies seek to produce more to order, which results in a reduction in the average batch size and a reconsideration of the way the production processes are planned and controlled. This reconsideration is subjective to specific food processing characteristics that were a main reason to produce in large batches in the past. These characteristics still exist and answers have to be found how to deal with the increasing product variety, more intense competition and higher logistical demands in the food processing industry.

Planning, controlling, and executing of operations in the food processing industry, is influenced by specific characteristics of the food processing industry. The most important product and production characteristics of the

food processing industry are perishability, shared resources (resources used by different production lines), sequence dependent setup times, connectivity (limited intermediate storage), variable demand for end products and a divergent product structure (for details see e.g. Akkerman and Van Donk, 2009, Kiliç *et al.*, 2011). In order to find solutions that can deal with planning challenges in the food processing industry, these facets should be taken into account.

Huda and Chung (2002) bring forward that food processing systems have received little academic attention in the past and argue that more studies are needed to deal with the complexity of the industry. They refer to the complexity of combined continuous and discrete production layouts as an argument for the scarcity of papers. Moreover, other authors put forward that relatively little attention has been paid to studying the influence of the specific characteristics of process industries on models for execution, planning and control of operations (Flapper *et al.*, 2002, Van Donk and Fransoo, 2006). As far as we know little is done with the suggestions of the aforementioned authors. Therefore a lot of work can still be done to study whether these models fit to process industries and, if needed, to tailor them to the particular production settings in the industry. One way to do so is put forward by Van Donk and Fransoo (2006). They discuss the interaction between process industry characteristics, empirical studies, and production planning and control models in the development of theory. They state that studying combinations of these three aspects is a way to further develop the theory in the field. In this thesis we follow these suggestions by combining typical food processing industry characteristics, an empirical case setting and different models to generate more insight on planning in this industry.

So far, a limited number of studies have been carried out to study the effect product and production characteristics have on planning in food processing systems. However, most papers focused on a few aspects. Tsubone *et al.* (1996) study a batch-processing machine in the first stage and multiple process lines in the second stage. However, they do not model intermediate storage. Nakhla (1995) studies the dairy industry but does not take shared resources into account. Van Dam *et al.* (1998) study the tobacco industry but do not take perishability into account. Entrup *et al.* (2005) develop a model for production and scheduling in yogurt production systems. However, they consider storage limitations in an aggregate way. Akkerman (2007) studies a two-stage food processing system, and analyses the effects of limited intermediate storage, shared resources and perishability on the performance of a food processing system. However, he analyses these effects by considering simple models and basic sequencing rules. Akkerman suggests that investigating the other food processing

characteristics is an interesting topic for further research, especially the various sources of uncertainty. Kilic *et al.* (2011) present a deterministic mathematical model where the food processing industry specific characteristics of shared resources, limited intermediate storage, sequence dependent setup times and are all taken into account. However, production and demand uncertainties are also neglected in this study.

The approaches discussed above have yielded valuable insights into different aspects of planning in food processing industries. However, most studies are limited by the rather simplified situation, taking into account either a limited number of characteristics or ignoring important uncertainties. In this thesis we thoroughly study a case company in the food processing industry in which all the aforementioned process industry characteristics are present including the often-neglected production and demand uncertainties. Firmly based in an empirical context we study how production planning models can be tailored to these industry specific characteristics.

1.2 Dynamics of planning in dairy

As indicated at the start of the introduction, the planning of a dairy factory is affected by market circumstances and company decisions. Therefore, before we specify the research questions in this thesis, we first provide insight in the dynamics occurring in the dairy industry. Section 1.2 roughly describes the different forces that are at work on a world, a company and a factory level. Most attention in the thesis goes to the decisions on a factory level where the other levels are included to provide the relevant context in which these decisions are made.

1.2.1 The European and world market

Production volumes

In the beginning of the eighties, the milk market within the EU was further regulated to halt the increasing overproduction of milk and the related expenses of subsidising agricultural products. Since 1984 the amount of milk that a country within the European Union may produce is therefore limited by a yearly quatum. As a result, the production volumes in the EU were stable (on average the volumes slightly increased by 0,36% on a yearly base in the period 1999-2010, EuroStat). Contrary, the production volumes of the six largest milk producing countries outside the EU increased by 3.5% on a yearly base (period 2006-2008, Lei Report 2010-015, Table 3.1).

For seasonal and meteorological reasons, the supply of milk is not stable throughout the year. A strong increase in the milk supply can be observed in

Introduction

spring when calves are born and most of the cows start grazing in the fields. The milk supply diminishes in autumn as the cows return to their barns and farmers have to feed them, where another reduction occurs in the period before new calves are born (Figure 1.1). As a result, differences of up to 12% in the monthly supply of milk occur. On a world scale these effects are damped a bit due to the fact that leading milk producing countries are on both sides of the world resulting in opposing peak seasons.

Next to the seasonal variations, also meteorological variations occur. For example, the drought in Australia in 2007 led to a reduction in the production of milk by 9% where in the same year a flood in Argentina resulted in a reduction of 8%. Consequently, fluctuations of the supply of milk are inevitable and the related supply chains need mechanisms to cope with these fluctuations.

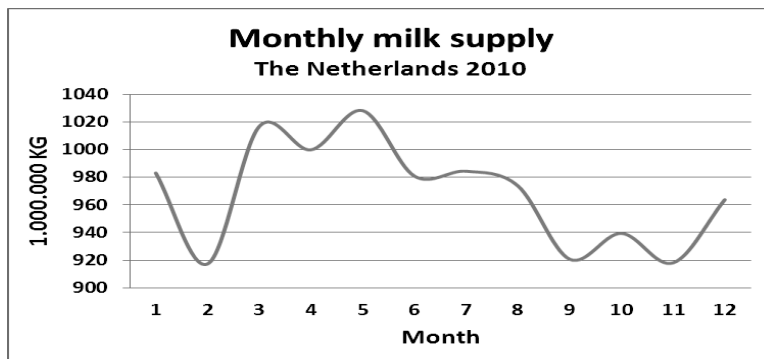


Figure 1.1: Monthly milk supply in the Netherlands (2010)

Data retrieved from CBS, www.cbs.nl, accessed on September 22, 2011.

Customer demand

The total demand for dairy products in Western countries is fairly stable. The number of residents in these countries slowly grows and dairy products are part of normal consumption habits. Changes in the price of milk only have a small effect on the demand for these products. On the contrary, the demand for dairy products in emerging markets in Asia and Africa show a volatile demand pattern. These markets are relatively sensitive for changes in the price of the product, where over the last 5 years (partly due to periods of drought) the prices doubled, halved and doubled again.

Prices

The subsidising of agricultural products combined with interventions at markets with a low selling price resulted in stable and relative high milk

prices in the EU. However the associated costs of the subsidies and interventions were perceived to be too high. Therefore, in the period 2001-2006, the EU dairy policy was reformed and intervention prices for butter and skimmed milk were reduced. As a result the milk prices gradually decreased (see Figure 1.2).

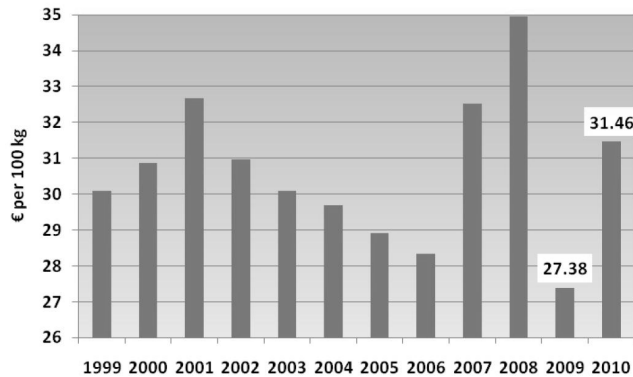


Figure 1.2: The average milk price based on 17 EU companies
(Source: LTO-International milk price comparison, www.milkprices.nl)

In 2006 the European Committee decided that in 2015 the subsidy of milk has to end and therewith also the production limitations caused by the milk quota. Because the patronage constructions of the EU cease, the prices in the European milk market will straightly follow the world market. As a consequence heavy fluctuations in price will become more common (see Figure 1.3 for the world market price fluctuations of last five years).



Figure 1.3: World market prices of Butter and milk powders
(Source: Royal FrieslandCampina Half-year Report 2011)

Regulating mechanisms

A number of regulating mechanisms dampen the fluctuations in the milk volumes, customer demand and market prices for dairy products. As indicated above, higher prices directly result in a drop in the demand for dairy products in emerging markets. At the same time, high prices for dairy products result in investment opportunities for farmers to enlarge their herd (mainly outside the EU due to the volume quota within the EU) and therewith increase the milk volumes (with a seasonal delay). Contrary, low prices result in the butchering of cows and market interventions in the EU (e.g. EU buying butter or skimmed milk). The intervention policies of the EU regulate prices. Not only prices increase due to the intervention in markets with a low price, but prices are also reduced when these purchased products are sold again. However, this mechanism only has a direct effect on price fluctuations in the EU and will be abandoned in 2015.

1.2.2 The company – Royal FrieslandCampina

Many dairy companies are cooperatives. Typical to cooperatives is that all the milk that is produced by the farmers needs to be allocated to the factories that supply the products to the customers. The push of the milk complicates production planning decisions. Non-cooperative companies like Nestlé only source the milk volume to produce products with margins above a predefined threshold or products with a strategic purpose. Cooperatives like FrieslandCampina (the case company in this thesis) have the obligation to accept all the milk even if there is no demand for products with an interesting profit margin. The decision to allocate the milk within in the company is to firstly allocate milk for premium branded products to fully meet the demand for these products. As the demand of these premium products does not absorb the total milk supply, the remaining milk is allocated in commodity products (e.g. skimmed milk powder or foil cheese) or products that are produced to stock in anticipation of future demand. One of the advantages of commodities over branded products is that there is always demand for these products avoiding the need to store the products in warehouses. However, the demand for these commodities fluctuates and is often at unattractive price-levels. So within the commodity products the aim is to maximise the revenue of remaining milk volume. The milk is therefore allocated based on the revenue for a milk equivalent (normalized quantity of fluid milk used in a processed dairy product) and the available production capacity. Higher revenues are desirable but volumes are limited by maximum production capacities. By this approach the milk push, and market pull are balanced in the allocation decision (Figure 1.4). As the number of allocation alternatives increase the allocation decision can be quite complex. For example, within FrieslandCampina the milk has to be allocated to approximately 50 factories.

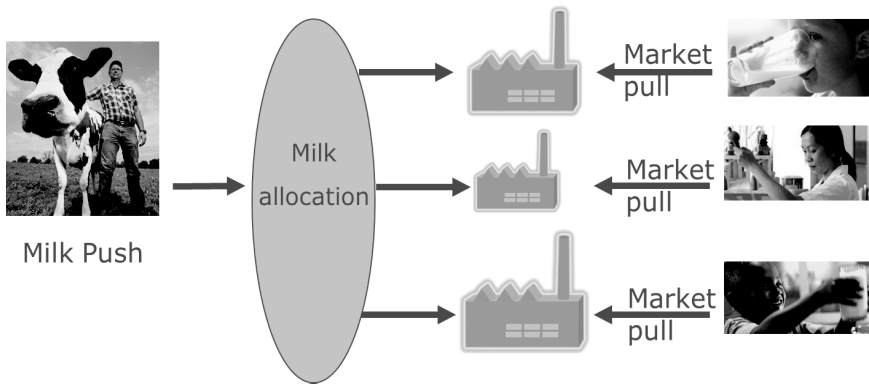


Figure 1.4: Milk push, market pull and milk allocation decision

1.2.3 The factory – condensed milk

Within a dairy factory, planning decisions are made on various levels, from long-term capacity decisions to daily adaptations of the production sequences. Below we discuss the main decisions that are made on the different planning levels.

Business planning

On a long range, decisions have to be made regarding the desired production capacity of the factory. Some production capacities are extended where other production capacities are reduced. These strategic decisions are based on the positioning of the factory within the market and within the company. These decisions often have a long time span. It could take up to a few years after the decision to increase the capacity has been made before the machine is fully operational.

Throughout the four years of the project a number of large changes happened in the case company. Investments in new machinery on one side (spray dryer, Pave blender, sachet packaging line) but also the termination of using production capacity (UHT sterilisers and packaging machines for bottles and cartons). From a theoretical point of view, just a change in the production capacity is not so interesting. Contrary, when a change in the production capacity or production technology affects the way the factory is planned, it is interesting to study the new planning approaches. Chapter 5 of the thesis discusses the example of the Pave technology (advanced blender). The new blending technology led to the redesign of the production sequences and therewith the way the production is planned. By postponing the product differentiation the production flexibility increases, which improves the way the company can compete in the market.

Sales & Operations Planning (S&OP)

Each month, the forecast of customer demand and the production capacity of the coming 18 months are balanced in S&OP meetings. One of its primary purposes is to establish production volumes throughout the periods that will achieve management's inventory and customer service objectives, while attempting to keep the workforce relatively stable (see APICS Dictionary (Cox and Blackstone, 2005) for the full definition of S&OP). Decisions on this horizon are required to plan the labour, equipment, facilities, material, and finances to accomplish the production plan. An example of a decision that is made on this level is whether to reduce the production load during the summer holidays (to avoid hiring temporary workers) by increasing stock levels in the months ahead of the holidays. Another decision is how to deal with the milk push or the scarcity of milk within the company; which products or product families could be used to deal with fluctuations in the milk supply.

Master Planning

On a weekly basis the planning of the following 13 weeks is reviewed and adapted. The master planner not only balances the production volumes (and therewith also roughly the labour needs) but also the mix of the products. Balancing the mix is especially important in the case company as sequence dependent set-ups in the processing phase have a large impact on the effective utilisation of the machines. Based on the 13 weeks forecast suppliers are informed how much the demand roughly is (e.g. for packaging materials and milk supply). However, as weeks pass by, the forecasted volumes are replaced by customer orders and week volumes are fixed as they enter the frozen period (the last weeks in which the planner normally does not adapt the volumes anymore). With the production volumes in the frozen period, orders can be placed at the suppliers.

On the master planning level an important distinction has to be made between make-to-order (MTO) and make-to-stock (MTS) products. For MTS products, the latest forecast is seen as the volume to be produced where the forecast of MTO products is removed when no official orders arrive. MTS products have a more reliable demand and are therefore used to smoothen weekly production volumes and to cope with fluctuations in the amount of milk in the company. However, a number of characteristics restrict whether a product can be made under the preferred MTS policy. For example, producing a product with a limited shelf life to stock that has a high variability in the demanded volume and a low accuracy of the forecast is probably a bad idea. The work of Soman (2005) provides insight in hybrid MTS-MTO production in food. However, it is still unclear how to construct an appropriate production strategy classification in the case company.

Therefore, Chapter 3 of the thesis addresses how SKUs (Stock Keeping Units) are classified on production strategy in the context of the case setting. However, while we explored the literature on this topic, previous contributions provided little guidance as they often lacked a structured approach. Therefore Chapter 3, which addresses the empirical setting, is preceded by Chapter 2 in which we thoroughly discuss how SKU classifications are structured. Moreover, Chapter 2 presents a framework on SKU classification and an overview on the techniques and characteristics included in the various classification approaches.

Scheduling and dispatching

The production volumes for the next two to four weeks (the frozen period) have to be scheduled on a specific day and time. Schedulers balance many opposing wishes (e.g. the processing department prefers a sequence based on recipes where the packaging department prefers a sequence based on packaging type) taking into account numerous production limitations (e.g. no banana flavour after strawberry). Based on the latest version of the production schedule, the dispatchers confirm the orders for packaging materials and set the desired time of arrival of the goods. For further details on how particular characteristics of the food processing industry affect scheduling decisions we refer to Chapter 4 in Kilic (2011).

Daily operations

Once the schedule is released to the floor, the execution of the schedule takes place. Throughout the week disturbances happen (e.g. machine failure, delayed delivery of packaging materials) that cause production managers to adapt the planning directly and to communicate to the schedulers who revise the production plan. Despite all kind of improvement efforts, the occurrence of disturbances can never be completely wiped out. Therefore appropriate buffering mechanisms are needed to minimise the impact of disturbances. In Chapter 5 we study how different safety buffers perform in dealing with different sources of uncertainty in demand and supply.

1.3 Research objective and approach

In process industries, including the food processing industries, markets are becoming more dynamic with greater competition and the need increases to mass customise products to customer needs (Shah, 2005). As a result it becomes more and more important to apply appropriate planning methods. Given that the food processing industry has typical characteristics which

Introduction

affect planning, the need increases to tailor theory on planning to the specific needs of the industry. The research objective of this thesis is therefore to understand how typical food processing characteristics affect the way planning is organised in food. To answer this question, we selected a number of planning topics that we study to understand how planning decisions are affected by these characteristics. As McGrath (1981) suggests, every study needs to make trade-offs between maximizing: A) generalizability with respect to populations; B) precision in control and measurement of variables related to the behaviour(s) of interest; and C) existential realism, for the participants, of the context within which those behaviours are observed (Figure 1.5). Given the limited attention paid to empirical studies combined with our interest in understanding how food processing characteristics affect planning, our main concern goes to maximising dimension C in order to provide insight in a real life situation. Therefore we chose for unobtrusive methodologies by which we study a particular behaviour system (Figure 1.5), namely the food processing industry. The main methodology we used throughout the chapters is the case study approach by which we conducted a field study in a company in the food processing industry. Next to the case study approach, computer simulation was used to increase the generalizability of our findings by studying related production settings.

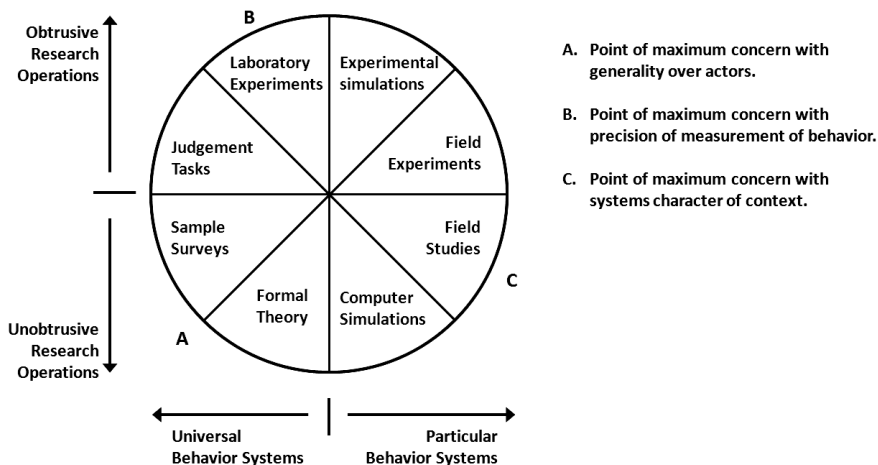


Figure 1.5: Research strategy model (adapted from McGrath, 1981)

1.4 Research questions and project selection

The subject of the thesis is planning in the food processing industry. Planning at different levels within a food processing factory deals with

effectively aligning customer demand and production capacity. The alignment is more than just smoothing the production load based on the maximum capacity while meeting the customer lead-times. Particular product and production characteristics affect the planning decisions that can be made. For example, the perishability of food products results in a limitation regarding the amount of product that can be stored without risking obsolescence of stock.

In this thesis we aim to understand how such characteristics affect the planning procedures in the food processing industry. Accordingly, the main research question in the thesis is:

How do food processing industry specific characteristics influence planning in the food processing industry?

Planning affects many decisions within a factory as described in Section 1.2.3. Studying all these decisions within the PhD project would be impossible and therefore we studied a number of specific research questions within our main research question. While studying these planning topics we have the ambitions as sketched by Guide and Van Wassenhove (2007) to be both scientific and practical relevant. Therefore the case company was involved in the selection of the projects. To guarantee and balance both the scientific and the managerial relevance, four times a year the project team, including top management from the company and researchers from the university, jointly evaluated the progress and determined further research directions. Three phases could be distinguished of the projects under consideration: i) exploration of the topic (both practical and theoretical), ii) the execution of the project including data collection, and iii) reporting the results in the right format for the different audiences (presenting the findings at management meetings and scientific conferences and publishing management reports and scientific papers). At each stage we evaluated whether it would be wise to continue to the next stage based on both the managerial and the scientific expectations. Our approach resulted in a large number of projects that we worked on during the four years the partnership lasted. In the thesis we report on four projects that we perceive as the most interesting from a scientific point of view.

Chapter 2 and Chapter 3 address the issue of SKU (Stock Keeping Unit) classification. Recently, Syntetos *et al.* (2009) stated that stock classification has been overlooked. They remark that the issue of classification has not received as much academic attention as the implications of the relevant decision-making in that area would require. Given the challenges in the case

company our main interest goes to SKU classifications on production strategy. Olhager (2003) summarizes a number of characteristics that influence the production strategy for individual products. Moreover, Van Donk (2001) and Soman (2005) indicate that particular food processing characteristics influence the production strategy of a SKU. However, despite these and other contributions we found that the literature on SKU classification does not provide an overview of the approaches nor does it aid practitioners with the question which production strategy to choose at different levels of these - sometimes conflicting - characteristics. The absence of structured guidance on how to come to a classification combined with the lack of insight how to deal with conflicting characteristics in production strategy classifications in food led us to research the following research questions:

- How can a SKU classification be structured? (Chapter 2)
- How are production strategy decisions (make-to-order or make-to-stock) of SKUs affected by food processing characteristics? (Chapter 3)

Chapter 4 addresses form postponement (FP) in the food processing industry. Several authors have stressed the relevance of product and production characteristics in the selection of the appropriate postponement strategy (Zinn & Bowersox, 1988; Pagh & Cooper, 1998; Van Hoek, 1999, 2001; Brun & Zorzini, 2009). Implementing FP in food is possible (Abukhader & Jonson, 2007, list over 50 examples) but it is hindered by a number of industry specific factors (Van Hoek, 1999; Yang *et al.*, 2004). So far, it is not clear under which circumstances FP is beneficial and to what extent the operational performance of implementing FP can be explained by typical characteristics of the food processing industry. Therefore we study the following research question:

- How is the operational performance of postponement decisions (delaying customer specification) affected by food processing industry characteristics? (Chapter 4)

Chapter 5 addresses buffering policies in the food processing industry. Typically, production stages in process industries are tightly coupled, with only a small amount of intermediate inventory available relative to the production speed (Taylor *et al.*, 1981). In such a situation, these systems are vulnerable to machine breakdowns and last minute changes in demand. Perishability of the intermediate products urges the food processing industry to use the appropriate buffering policy, as excess production capacity is often limited due to the capital intensity of production capacity. However, it is unclear which buffer policy to use in different circumstances

and how this decision is affected by typical food processing industry characteristics. Therefore our final research question is:

- What is the appropriate buffering policy under different sources of uncertainty and how is this decision affected by food processing industry characteristics? (Chapter 5)

By studying the research questions indicated above we aim to understand how planning in the food processing industry is affected by characteristics of the food processing industry. In Table 1.1 we summarise how the most common typical food processing characteristics (based on Akkerman and Van Donk, 2009) are present in Chapter 3-5 of the thesis.

Table 1.1: The presence of the six most common typical food processing characteristics in the chapters of the thesis

Characteristic	Chapter 3: SKU classification	Chapter 4: Form Postponement	Chapter 5: Buffering strategies
Perishability	Limited shelf-life forces SKUs with a low forecast accuracy to become MTO	-	Perishability of the recipe is one of the reasons for last minute changes in the demand
Shared resources (resources used by different production lines)	Slave SKUs which use a common and shared recipe have nearly the same ordering possibilities as Master SKUs	Processing feeds multiple packaging departments (the simulation only explores a 1-1 relation)	-
Sequence dependent setup times	Regular recipes mostly have short set-up times. For MTO products this results in shorter lead-times	The sequence dependents set-ups in processing are overcome by implementing FP	-
Connectivity (limited intermediate storage)	-	The postponed process design changes the storage needs compared to the traditional layout	Intermediate storage is limited and therefore inventory levels are part of the objective function
Variable demand for end products	Forecast accuracy is an important distinguisher between MTO and MTS	Implementing FP makes production more responsive	Different sources of demand uncertainty are included in the model
Divergent product structure	-	Implementing FP adapts the product flow but it remains divergent	-

1.5 Generalizability of results

The food processing factory, which we study in most chapters of the thesis, shows all the distinctive characteristics of the food processing industry (see Section 1.1 for details on these characteristics). Therefore we used this factory as a “typical case” of this industry (Yin, 2003 p. 41-43). The collaboration with the case company provided us excellent research opportunities to study product and production characteristics and their effect on planning decisions and operational performance of the system. Given that all the typical characteristics were present (which is not the case in all food processing companies) we argue that these findings are relevant for more factories than just this factory. The planning issues addressed in the thesis are common in food processing and to some extent in the wider processing industries as well. Therefore our results can be used to improve operational performance in food processing industry and other process industries as well.

1.6 Thesis outline and included publications

Chapters 2 – 5 consist of four papers that are published or accepted for publication addressing the four research questions indicated in Section 1.4. The four papers relate to each other but in the way they are written, they can be read as individual contributions. Reading Chapter 1 entirely before reading these papers is recommended as it provides a description of the theoretical and empirical background in which the research took place. Finally, Chapter 6 discusses our main findings and provides directions for further research and collaboration with industry.

Chapters 2-5 subsequently contain the following publications:

- 2) Van Kampen, T.J., R. Akkerman and D.P. van Donk (2012), SKU classification: A literature review and conceptual framework, *International Journal of Operations & Production Management*, forthcoming, Vol 32, No. 7
- 3) Van Kampen, T.J. and D.P. Van Donk (2011), Dynamics of SKU classification: the production strategy in a dairy company, *proceedings of the 18th Annual EurOMA Conference*, Cambridge, United Kingdom.

- 4) Van Kampen, T.J. and D.P. Van Donk (2010), Form postponement in the food processing industry: the case of a dairy company, proceedings of the 17th Annual EurOMA Conference, Porto, Portugal.
- 5) Van Kampen, T.J., D.P. Van Donk and D. J. Van der Zee (2010), Safety stock or safety lead-time: coping with unreliability in demand and supply, International Journal of Production Research, Vol. 48, No. 24, pp. 7463-7481.

2. SKU classification: A literature review and conceptual framework¹

Abstract

Stock Keeping Unit (SKU) classifications are widely used in the field of production and operations management. Although many theoretical and practical examples of classifications exist, there are no overviews of the current literature, and general guidelines are lacking with respect to method selection. This paper systematically synthesises the earlier work in the area, and conceptualises and discusses the factors that influence the choice of a specific SKU classification. Therewith this paper aims to advance the literature on SKU classification from the level of individual examples to a conceptual level and provides directions on how to develop a SKU classification. Through our structured approach we found that SKUs are classified based on the classification aim, the context and the method that is chosen. Within the method three decisions are identified to come to a classification: the characteristics, the classification technique and the operationalization of the classes. A theoretical implication of our findings is that future research could use our conceptual framework to develop guidelines for real-life applications. Practitioners can use the general directions we summarise and the examples we identified from a variety of industries to develop their own SKU classification.

2.1 Introduction

In production and operations management, companies often have to deal with many different products, or Stock Keeping Units (SKUs). Here, SKUs refer to items of stock that are completely specific as to function, style, size, colour, and, usually, location (Silver *et al.*, 1998, p. 32). The production and inventory policies of these different SKUs are influenced by the characteristics of the product. Differences in annual sales volume, predictability of demand, product value, or storage requirements might result in different production and inventory policies. As a consequence,

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companies that sell a wide variety of SKUs often struggle with the control of their production and inventory systems. Therefore, in real-life situations, it is generally seen as advantageous to distinguish a limited number of SKU classes based on the characteristics of these SKUs. This enables companies to make decisions on production strategy (e.g. make-to-stock or make-to-order), production and inventory management and customer service for entire SKU classes rather than for each product separately.

In order to create a SKU classification, two simple questions need to be answered: how many classes are used and how are the borders between the classes determined. Various approaches and techniques exist to classify SKUs. A well-known approach is the ABC analysis, which usually classifies product groups based on either demand value or demand volume. Another well-known approach is the FNS technique, which distinguishes product classes based on demand rate (Fast, Normal, and Slow). Empirical studies seem to use approaches inspired by the specific context, and it is often far from clear why a certain method was employed or whether other approaches could also have been used. Technical papers provide and develop analytical tools to classify SKUs, but it remains unclear under what circumstances or context they should be applied. It seems that there is a lack of guidance as to which techniques should be used to classify SKUs and which characteristics should be included under specific circumstances.

In the absence of papers that provide an overview of contributions on SKU classification, combined with a lack of papers that structure the classification process there is no guidance for academics and practitioners on this topic. Syntetos *et al.* (2009) confirm that classification has not received sufficient academic attention given the implications of the decision-making in that area. Therefore, the aim of our paper is to structure the previous work on SKU classification in order to provide directions on how SKU classifications can be designed. Our review explores what factors drive choices in SKU classifications and what techniques are appropriate in different circumstances. We argue that much can be gained in research and practice by knowing these factors and their relationships.

The first step in our approach is to systematically review the existing SKU classifications and to identify the aims, techniques used, and SKU characteristics adopted. The insights gained are used to discuss how different factors influence a SKU classification. The outcome of this step is expressed in a conceptual framework that supports the design of SKU classifications and provides the basis for further theory building. The outcomes of our study also have practical relevance as they might guide managers in selecting an appropriate method for classifying SKUs.

The paper is structured as follows. The next section further introduces SKU classification and elaborates on the main research questions.

Subsequently, we describe the research approach, and present the results from the literature survey. In the final parts of the paper, the results are discussed and conclusions are drawn.

2.2 Motivation and research questions

The main aim of any SKU classification is to use the similarity of products with regards to different properties to systematically classify products. Krishnan and Ulrich (2001) identified four perspectives within the academic community from which product properties are studied: marketing, organizations, engineering design, and operations management. In this paper we focus on the classification of products from the production and operations management perspective.

Within production and operations management, inventory management and forecasting are fields where a variety of SKU classifications is traditionally used to support decision-making. One of the oldest and best-known classification approaches is the ABC analysis that is used in inventory management (see Silver *et al.* (1998) for the technique, Schomer (1965) for an early application or Zhang *et al.* (2001) for a spreadsheet extension). The aim of the ABC analysis is that, if one focuses on the relatively small number of products that represent a major part of the sales volume (i.e. the A products), relatively large reductions in inventory costs can be obtained. This builds heavily on the insights advanced by Pareto (1906). However, some authors argue that cost reductions mainly occur through the appropriate treatment of the C products (see Viswanathan and Bhatnagar, 2005; Teunter *et al.*, 2010 for a discussion on the topic). Other characteristics than volume are also used in classifications for inventory management. For example, the XYZ technique differentiates, as with the ABC technique, between three categories of products, but this time based on variability in demand (see Schönsleben, 2003). These basic techniques are widely used and have been implemented in commonly used software tools, such as SAP's ERP and APS software (Hoppe, 2006), to make it easier for practitioners to tailor production and inventory activities to the demand characteristics of their products.

SKU classification is also frequently used in forecasting. Selecting the proper forecasting method is important to be able to balance the costs of keeping inventory and the risk of stock-outs. The latter aspect is especially important in controlling spare parts due to the impact the absence of a spare part can have (see Cavalieri *et al.* (2008) for an overview on the management of spare part inventories). Here, the demand is generated by the process requiring the spare parts, often leading to a situation where there is only an occasional need for a certain part. The reliance of the

production process on the availability of the specific spare parts is an important consideration in managing spare part inventories where forecasting these low volumes is difficult. Therefore, the selection of the appropriate forecasting techniques for spare parts is an important decision that can be supported by a SKU classification (see Syntetos *et al.*, 2005; Boylan and Syntetos, 2008).

SKU classification is not limited to inventory management and forecasting. They are also used to determine the production strategy. Several contributions have been made in this respect. For instance, Hoekstra and Romme (1992) classify SKUs to decide whether to make them to stock or to order. The related issue of finding the right level of postponement for different product classes was studied by Pagh and Cooper (1998). In the same decade, Fuller *et al.* (1993) discussed the tailoring of logistics, and Fisher (1997) discussed the appropriate supply chain for a specific product. Numerous authors followed these seminal works, e.g. by refining the classification methods presented (Stavrulaki and Davis, 2010), by developing industry-specific frameworks (Soman *et al.*, 2004), or by demonstrating the value of using classification methods (Christopher *et al.*, 2009). Between the above-mentioned works, there are obviously differences in focus and in the characteristics that are used, but all are based on some kind of classification of SKUs and they all provide insights in relation to production strategy.

The characteristics that are used to classify SKUs are numerous. Examples of characteristics that are used in different approaches are volume and variability (D'Alessandro and Baveja, 2000), different types of variability (Talluri *et al.*, 2004), unit cost, dollar value, criticality and lead-time (Ramanathan, 2006), duration of life cycle, time window for delivery, volume, variety, and variability (DWV³) (Childerhouse *et al.*, 2002; Christopher *et al.*, 2009).

Syntetos *et al.* (2009) study spare part management and state that stock classification has been overlooked. They remark that the issue of classification has not received as much academic attention as the implications of the relevant decision-making in that area would require. We would argue that this is not only the case for spare parts but for SKUs in general. Even though many applications can be found, no overview exists of the applications or techniques that can be used. As a consequence, there is a lack of guidance for practitioners who want to use a SKU classification within productions and operations management. At the same time the existing applications are often based on, or inspired by, a certain production environment (e.g. D'Alessandro and Baveja (2000) use a specific batch sizes to distinguish classes), and it is not always clear if an approach has wider applicability.

In the absence of structural guidance on SKU classification and the scattered applications found in the literature we argue that it is appropriate to synthesize the existing work and strive towards a conceptual foundation for SKU classification. A systematic review of the literature on applications of SKU classification will provide the ingredients to build such a foundation. Further, we aim to provide guidance on how SKUs can be classified. From the above discussion four main research questions emerge:

- RQ1: What are the aims in SKU classification?
- RQ2: Which characteristics are used to classify the SKUs?
- RQ3: Which classification techniques are used?
- RQ4: How is the classification influenced by the context?

The answers to the above questions will provide the building blocks for a conceptual framework along with a basis for theory building. Meredith (1993) provides two necessary conditions for external validity of conceptual frameworks. The first one (it should be based on earlier studies) is rather straightforward as we conduct a systematic literature review. The second one (it should be based on real world descriptions) is taken into account by mainly considering descriptions of applications of SKU classification in the literature.

2.3 Research method and data analysis

There are numerous situations in which SKU classifications are used. In our review, we focus on contributions to the production and operations management literature. In many papers, SKU classification is not an aim in itself but an approach adopted to achieve another aim (e.g. a SKU classification is used to minimize the inventory value). As such, it is a challenge to find papers that classify SKUs, and also to cover the entire scope in which classification studies might be found. To address the challenge, a broad, structured literature review was conducted. Using the ISI Web of Science database (with subject areas 'management' and 'operations research & management science') enabled us to cover not only influential journals in the field of production and operations management but also journals in adjacent fields. Since SKU classification is often not the main topic of a paper we searched for combinations of keywords in a single sentence to find potentially relevant papers. We used primary keywords related to the object to be classified (e.g. demand, product, ABC, SKU) and secondary keywords related to the classification process (e.g. classification, characterisation, category). The secondary keyword 'analysis' was only

used in combination with 'ABC' as the primary keyword, as coupling it with other primary keywords mainly lead to inappropriate papers such as ones on product analysis. Table 2.1 lists all the keywords used. Our initial search resulted in 479 papers in 85 journals (search conducted October 2008).

Table 2.1– Keywords used in primary search

Primary keywords	Secondary keywords
SKU, Product, Products, Demand, ABC	Classification, Classifying, Categorization, Categorisation, Categorizing, Categorising, Characterization, Characterisation, Characterizing, Characterising, Category, Categories, Segregation, Segregating, Classes
ABC	Analysis

In the initial selection, the primary and secondary keywords appeared in a single sentence in either the abstract or the title. In a further filtering, our main aim was to check whether these papers actually dealt with the classification of SKUs, or whether these words just happened to appear together. In other words, we checked whether the secondary keyword actually related to the primary keyword. As a result, the majority of papers were rejected, and only 91 papers were retained for possible inclusion in the review. Many of these papers did use various SKU classifications (for example, papers on inventory rationing would use a customer's price setting as their basis) but did not discuss how they came to these classes, and were therefore excluded. As a consequence, this phase reduced our initial selection to 20 papers. Due to the fact that older publications are not always fully indexed in the ISI database, the literature discussions in these 20 papers were investigated to find references to other studies on SKU classification. In our search for additional papers, we focused on contributions that outlined and applied SKU classification techniques. An additional 54 papers were thus considered, of which 25 were selected for inclusion after a further check of the papers. Therefore, our final selection amounted to 45 papers. The structured literature review is schematically summarised in Figure 2.1.

The papers that were included were read by the authors and a number of details were distilled to answer the research questions. These were: the aim behind the SKU classification (RQ1), the characteristics upon which the classification was based (RQ2), the classification technique used (RQ3), and finally the industry in which the classification was performed and related context-specific aspects, when present (RQ4). Whenever there were doubts regarding one of these attributes this was discussed between the authors.

SKU classification framework

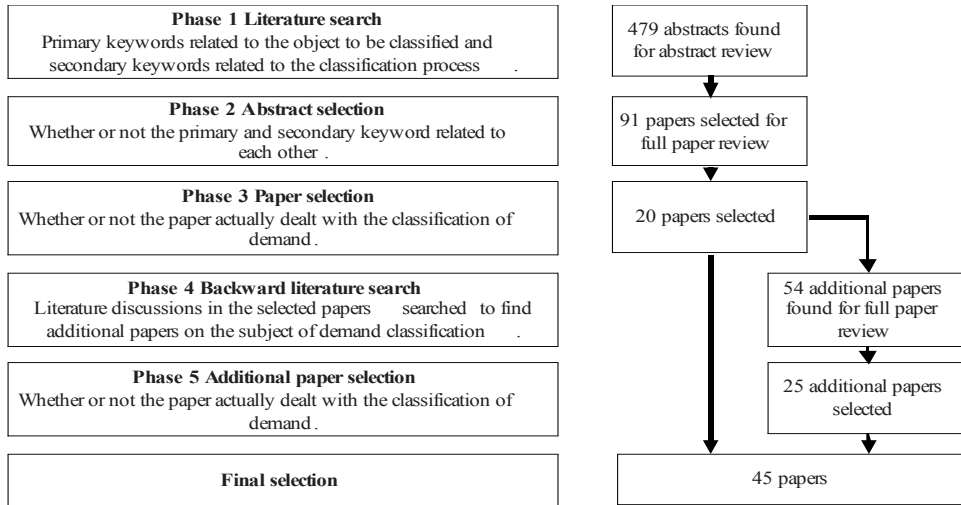


Figure 2.1: Systematic selection of papers on SKU classification

In the introduction and motivation sections three aims (RQ1) were already identified for classifying SKUs: inventory management, forecasting and production strategy. In the analysis of the papers these aims are used as a starting point to discuss the reasons to classify SKUs.

The characteristics that were collected for RQ2 showed a great diversity. In order to compare the different approaches and to structure the outcomes we used a number of categories. Existing literature provided different categories to characterize SKUs in different situations. Fuller *et al.* (1993) aim to tailor logistic processes to the wishes of customers. They presented eight questions/dimensions to analyse whether a product is shipped according to a logistically distinct method (Fuller *et al.*, 1993, p. 93). Bartezzaghi *et al.* (1999) studied how demand lumpiness is generated by different market characteristics and provide five classification dimensions. Christopher and Towill (2000) came up with five characteristics that influence the design of value stream delivery strategies. In the presence of the variety of structures to classify products from various perspectives we tried to come up with a general structure. As SKU characteristics mainly result from customer demand and the characteristics of the product, we based our categories on the concept of a customer order for a product. We define the order as a demanded *amount* of a *product* by a *customer* at a moment in *time*. From this, we identified four main characteristics in SKU classification: *volume*, *product*, *customer* and *timing*. The abovementioned characteristics used by Fuller *et al.* (1993), Bartezzaghi *et al.* (1999) and Christopher and Towill (2000) can be grouped by our four main characteristics (see Table 2.2). By using these four main characteristics we

expect to be able to frame most of the characteristics used for a SKU classification from a production and operations management perspective.

Table 2.2 – Main characteristics in SKU classification related to previous studies

Main characteristic	Fuller <i>et al.</i> (1993)	Bartezzaghi <i>et al.</i> (1999)	Christopher and Towill (2000)
Volume	Sales volume, order size	Variety of each customer's request (CoV of demand)	Volume, variability
Product	Profit margin, relations to other products, services included with delivery, handling and storage requirements, substitutability		Variety, duration of life cycle
Customer		Numerousness of customers, heterogeneity of customers, correlation between customers behaviour	
Timing	Delivery speed/window/frequency	Frequency of order placing	Time window for delivery

A large variety of techniques (RQ3) can be used to come to a classification. To structure these techniques we looked at the type of data needed for each approach. In relation to forecasting, Armstrong (2001, p. 9) identified the special character of judgemental knowledge sources as opposed to statistical knowledge sources. Assuming that such a general distinction would also be relevant for inventory management and production strategy, we use this distinction to categorize the techniques found in the papers in being based on either (*i*) judgemental or (*ii*) statistical data sources.

For RQ4 we tried to identify how the context influences a classification of SKUs. However, given the broad explorative nature of the question, no direct rules could be established upfront. Therefore, we decided to list what is reported in the papers related to the specific context and tried to structure and discuss the emerging findings in the results and discussion section. To give an initial indication of context, we listed the industry in which the approach was applied.

2.4 Results

The purpose of classification schemes is to determine the number of classes and the borders between the classes. This is done through the specification of the classification parameters and their cut-off values. Opposed to the seemingly simple nature of the purpose a multitude of alternatives exist to do so. Table 2.3 lists the papers that were selected in our search process, including information on the aim of the SKU classification, the industry in which the technique was applied, and details relating to the four characteristic categories we have identified (*volume*, *product*, *customer* and *timing*). In line with the traditional ABC approach, quite a few papers use the (annual) demand value, which is a combination of two characteristics from different categories: *volume* and *product*. For clarity reasons we therefore split this into demand volume and unit cost. To create uniformity in the overview, we sometimes slightly adapted the terminology used in the papers. For example, annual demand rate (Gelders and Van Looy, 1978), annual sales (Huiskonen *et al.*, 2005), demand volume (Partovi and Hopton, 1994), monthly demand (Porrás and Dekker, 2008) have been made uniform by using demand volume where we put the specific period between brackets. In the following subsections, we will discuss the results following the four research questions posed in Section 2.2.

2.4.1 Classification aims

Various reasons for classifying SKUs can be found in the papers in our sample. Table 2.3 shows that most of the work is applied in inventory management or, to a lesser extent, in forecasting. Few papers have a wider scope and use SKU classification to support decision-making on an appropriate production strategy.

The inventory management contributions mainly set out to determine order/production quantities, reorder points, safety stock, etc. for different SKU classes. The characteristics on which the classes are determined vary, and will be discussed in the next section. In many examples, SKU classes are used to reduce inventory levels by focusing on the fast moving stocks (similar to the ABC analysis). However, when all the products are slow movers (as with spare parts), SKU class selection is influenced by other characteristics (Flores and Whybark, 1987; Williams, 1984; Eaves and Kingsman, 2004). Studies that apply specifically to slow moving spare parts are indicated in Table 2.3 by '(spare parts)' alongside the industry description. Here, the category *customer* does often not relate to external customers but to the internal production process that in most situations only has an occasional need for the spare parts.

Table 2.3 – Summary of studies on SKU classification

Study	Aim	Industry	Characteristics			
			Volume	Product	Customer	Timing
Aitken <i>et al.</i> (2003)	PS	Lighting	Demand volume	Product variety, order winners, market qualifiers, product life cycle	-	-
Bhattacharya <i>et al.</i> (2007)	IM	Pharmaceutical industry	Demand volume (daily)	Unit costs, lead-time, perishability, storage costs	-	-
Boylan <i>et al.</i> (2008)	IM/ FOR	Automotive, aerospace, chemical	Demand volume (mean+ Coefficient of Variation (CoV))	-	-	Mean inter-demand interval
Canen and Galvao (1980)	IM	Manufacturing	Demand volume* (annual)	Unit cost*	-	-
Canetta <i>et al.</i> (2005)	IM	Electronics - component inventory	Demand volume (monthly (mean + CoV))	Commonality, supply lead-time (mean + CoV), unit cost	-	Frequency
Cavaliere <i>et al.</i> (2008)	IM	Process industry (spare parts)	Demand volume	Unit cost	Criticality, number of installations	-
Chakravarty (1981)	IM	General	Demand volume	Unit cost	-	-
Chen <i>et al.</i> (2008)	IM	General	Demand volume* (annual)	Unit cost*, criticality, lead-time	-	-
Chrisman (1985)	IM	Cylinder parts	Demand volume* (annual)	Unit cost*	-	-
D'Alessandro and Baveja (2000)	PS	Chemical	Demand volume (weekly, mean + CoV)	-	-	-
Duchessi <i>et al.</i> (1988)	IM	Spare parts	Demand volume* (annual)	Unit cost*	Criticality	-
Eaves and Kingsman (2004)	FOR	Air Force	Demand size variability	Lead-time variability	-	Transaction variability
Ernst and Cohen (1990)	IM	Automotive (spare parts)	Demand volume (monthly, mean + CoV), Returns volume (annual)	Unit cost, product life cycle, lead-time (actual + later+ CoV), used in number of vehicles	Criticality	Seasonality factor
Fisher (1997)	PS	General	Demand predictability	-	-	-
Flores and Whybark (1986)	IM	Manufacturing	Demand volume*	Unit cost*, lead-time	-	-
Flores and Whybark (1987)	IM	Manufacturing and service firm (spare parts)	Demand volume*	Unit cost*	Criticality	-
Flores <i>et al.</i> (1992)	IM	General	Demand volume* (annual)	Unit cost*, unit cost (mean), lead-time, criticality (scarcity, substitutes)	Criticality (impact)	-
Gajpal <i>et al.</i> (1994)	IM	Manufacturing (spare parts)	-	-	Criticality (alternative production facility available, availability of spare parts, lead-time)	-
Gardner (1990)	FOR	Military (spare parts)	Demand volume	Unit cost	-	-
Gelders and van Looy (1978)	IM	Petrochemical industry	Demand volume (annual)	-	-	-
Ghobbar and Friend (2002)	FOR	Aviation (spare parts)	Demand size (squared CoV)	-	-	Mean inter-demand interval
Güvenir and Erel (1998) (example 1)	IM	University	Demand volume* (annual)	Unit cost*, lead-time	Replaceability	Number of requests for the item in a year

Table 2.3 continued – Summary of studies on SKU classification

Study	Aim	Industry	Characteristics			
			Volume	Product	Customer	Timing
Güvenir and Erel (1998) (example 2)	IM	Mining	Order size requirements	Unit cost, lead-time, scarcity, durability, substitutability, reparability, stockability, commonality	-	Number of requests for the item in a year
Harhalakis <i>et al.</i> (1989)	IM	Infant care equipment	Demand volume* (monthly)	Unit Cost*, unit volume	-	-
Hautaniemi and Pirttilä (1999)	IM	Assembly	Demand volume* (annual), demand pattern (singular/lumpy/continuous)	Unit cost*, supplier lead-time (in relation to time needed)	-	-
Huiskonen (2001)	IM	Spare parts	Demand volume	Specificity, unit cost	Criticality	Inter-demand interval predictability
Huiskonen <i>et al.</i> (2005)	IM	Construction company	Demand volume (annual)	Annual sales of A/B products in the same order as the C-product	Proportion of C product sales to customer types	Number of orders (annual)
Kobayaci and Liang (1999)	IM	High-tech manufacturing and airline (both spare parts)	Demand volume (mean + variance), randomness	Lead-time (mean + variance)	-	Seasonal patterns, trend
Mukhopadhyay <i>et al.</i> (2003)	IM	Mining (spare parts)	Demand volume (annual)*, during replenish lead-time	Unit cost*	Criticality to production process	-
Ng (2007)	IM	General	Demand volume* (annual)	Unit cost*, lead-time	-	-
Onwubolu and Dube (2006)	IM	Mining	Demand volume* (annual)	Unit cost*	-	-
Partovi and Anandarajan (2002)	IM	Pharmaceutical industry (spare parts)	Demand volume (annual)	Unit cost, ordering cost, lead-time	-	-
Partovi and Burton (1993)	IM	Pharmaceutical industry (spare parts)	Demand volume (annual)	Unit cost, lead-time	Criticality	-
Partovi and Hopton (1994)	IM	General (spare parts)	Demand volume	Unit cost, lead-time	Criticality	-
Porras and Dekker (2008)	IM	Oil refinery (spare parts)	Demand volume (monthly)	Unit cost	Criticality	-
Portugal (2002)	FOR	Catalogue fashion retailing	Demand volume	Profit margin	-	-
Ramanathan (2006)	IM	General	Demand volume* (annual)	Unit cost*, criticality, lead-time	-	-
Reid (1987)	IM	Health care	Demand volume (annual)	Unit cost	-	-
Ritchie and Kingsman (1985)	IM	Wholesaling	Demand volume (weekly, empirical distribution)	-	-	-
Sani and Kingsman (1997)	FOR	Agricultural machinery (spare parts)	Demand volume (annual)	-	-	-
Stanford and Martin (2007)	IM	Machine parts	Demand volume (annual)	Unit cost	-	-
Syntetos <i>et al.</i> (2005)	FOR	Automotive	Demand size (squared CoV)	-	-	Mean inter-demand interval
Williams (1984)	IM/ FOR	Public utility	Demand (lumpiness)	-	-	Mean number of lead-times between demands, variance of lead-time
Wu <i>et al.</i> (2006)	FOR	Short lifecycle tech products	Demand pattern (lifecycle)	-	-	-
Zhou and Fan (2007)	IM	General	Demand volume* (annual)	Unit cost* (mean), lead-time	-	-
Aim = The dominant application purpose: Inventory Management (IM), Forecasting (FOR) or Production Strategy (PS) The study uses (annual) demand value; we have converted this to demand volume and unit cost						

Aim = The dominant application purpose: Inventory Management (IM), Forecasting (FOR) or Production Strategy (PS)
 * The study uses (annual) demand value; we have converted this to demand volume and unit cost

The second largest classification aim is related to forecasting methods. Here, the classification of SKUs facilitates the selection of an appropriate forecasting method for the determined product classes (Syntetos *et al.*, 2005). An important aspect in these studies is the demand pattern over time. Whether the demand pattern is smooth, sporadic or lumpy greatly influences the performance of the different forecasting methods. A specific situation is the forecasting of slow moving products, which often have an intermittent and erratic demand pattern (Boylan and Syntetos 2008, p. 484).

In relation to production strategy, several issues are addressed. Aitken *et al.* (2003) focus on product lifecycles and the resulting differences in supply chain strategy for associated products. D'Alessandro and Baveja (2000) use a product classification to choose between different distribution channels, including customer prioritisation and make-to-order or make-to-stock decisions. Fisher (1997) aims to determine the best supply chain for a product, largely based on demand predictability. His main idea is to use a physically efficient, lean, make-to-stock supply chain for predictable demand, whereas unpredictable demand should be handled within a market-responsive, agile, make-to-order supply chain. Similar guidelines are provided by Li and O'Brien (2001) and Vonderembse *et al.* (2006).

2.4.2 Characteristics used for SKU classification

As explained in Section 2.3, we distinguish four main categories for SKU characteristics: *volume*, *product*, *customer* and *timing*. In terms of *volume*, most authors include the demand volume over a certain period in their classification, often in combination with unit cost to calculate the demand value. Especially for applications in inventory management, demand value often reflects inventory investment and it is argued that products with high values warrant special attention. However, according to Flores and Whybark (1987), very little specific guidance has been given on how to actually pay 'special attention' and improve performance. Alongside the absolute volume, a number of authors (e.g. D'Alessandro and Baveja, 2000; Ernst and Cohen, 1990) also include the variability in volume, mostly by calculating a Coefficient of Variation (CoV) over several demand periods (e.g. weekly, monthly). Other authors suggest analysing the volume of individual orders (e.g. Ghobbar and Friend, 2002; Kobbacy and Liang, 1999; Syntetos *et al.*, 2005). Our overview shows a limited number of such papers, and data on individual orders seems to be used mostly in relation to forecasting. However, this does not imply that studies in forecasting only use data on individual orders. Finally, some alternative approaches have been proposed within the category *volume*. For example, Wu *et al.* (2006) try to identify demand patterns over a product's lifecycle, to improve

forecasting for other products. Here, the focus is thus not only on absolute volumes but also on how these volumes evolve over a product's lifecycle.

The second category, *product*, is found in most papers. Related to our earlier remark on the frequent use of demand value, the product's unit cost is one of the most common characteristics used. However, we did find a large range of other characteristics in this category, such as lead-times related to production or supply. Further, context-specific characteristics such as product perishability, commonality and substitutability have also been used.

The third category, *customer*, is not used often. Huiskonen *et al.* (2005) provide an example where the importance of the customer is used. In their approach C products (in the ABC classification) become more important to meet customer requirements if they are sold to important customers or have a relation to A products. Further, the use of *customer* characteristics seems limited to the classification of spare parts. This reflects the importance of that part to the customer, where it should be reiterated that the customer of a spare part is often the internal production process. Criticality reflects the effects and financial consequences of not being able to deliver a spare part within the required lead-time. The criticality may be determined informally by the insight of an expert (e.g. the VED classification, which labels products as vital, essential or desirable) or by more formal methods such as failure mode effects and criticality analysis (FMECA, see Boylan and Syntetos, 2008) or the analytical hierarchy process (AHP, see Gajpal *et al.*, 1994).

The final category, *timing*, seems relatively neglected in literature. The most notable measure used is the inter-demand interval. The measure gives an insight into the frequency of orders, and can be used to estimate when a next order for a product can be expected. It is therefore not surprising that the studies including such *timing* aspects tend to be those focused on forecasting. Johnston and Boylan (1996) were the first who formally established the importance of the inter-demand interval as a classification parameter. A few authors have investigated other *timing* related characteristics. Examples are SKU classes based on seasonality or trends (e.g. Ernst and Cohen, 1990; Kobbacy and Liang, 1999).

2.4.3 Techniques used for SKU classification

The papers we studied show a large variety in techniques to come to a classification (see Table 2.4). As introduced in Section 2.3, we distinguish between two types of knowledge sources: (i) judgemental and (ii) statistical. Techniques based on expert judgement are ways to capture the opinions of managers. Statistical knowledge sources are based on data of a number of SKU characteristics. Within the statistical techniques there is a

wide variety in the complexity of the technique and in the number of characteristics used. In Table 2.4 they range from simple guidelines based on a limited number of SKU characteristics to advanced mathematical models that can more easily deal with a large number of SKU characteristics.

Table 2.4 – Summary of SKU classification techniques used

Knowledge source	Technique	Study
Judgemental	VED	Cavalieri <i>et al.</i> (2008), Mukhopadhyay <i>et al.</i> (2003)
	AHP	Flores <i>et al.</i> (1992), Gajpal <i>et al.</i> (1994), Partovi and Burton (1993), Partovi and Hopton (1994)
	TOPSIS	Bhattacharya <i>et al.</i> (2007)
Statistical	Distance modelling	Chen <i>et al.</i> (2008)
	Traditional ABC/Pareto analysis	Canen and Galvao (1980), Chrisman (1985), Gardner (1990), Gelders and Van Looy (1978), Mukhopadhyay <i>et al.</i> (2003), Onwubolu and Dube (2006), Portougal (2002), Reid (1987), Sani and Kingsman (1997)
	FSN/FNS	Cavalieri <i>et al.</i> (2008), Gelders and Van Looy (1978), Mukhopadhyay <i>et al.</i> (2003)
	Bi-criteria ABC	Cavalieri <i>et al.</i> (2008), Flores and Whybark (1986), Flores and Whybark (1987), Harhalakis <i>et al.</i> (1989)
	Graphical/2x2 matrix	D'Alessandro and Baveja (2000), Ghobbar and Friend (2002), Syntetos <i>et al.</i> (2005), Williams (1984).
	Decision tree	Boylan <i>et al.</i> (2008), Eaves and Kingsman (2004), Hautaniemi and Pirttilä (1999), Huiskonen (2001), Kobbacy and Liang (1999), Porras and Dekker (2008)
	Typical profiles	Aitken <i>et al.</i> (2003), Fisher (1997), Ritchie and Kingsman (1985)
	Cluster analysis	Canetta <i>et al.</i> (2005), Duchessi <i>et al.</i> (1988), Ernst and Cohen (1990), Wu <i>et al.</i> (2006)
	Optimisation techniques	Chakravarty (1981), Ng (2007), Ramanathan (2006), Stanford and Martin (2007), Zhou and Fan (2007)
	Neural networks	Huiskonen <i>et al.</i> (2005), Partovi and Anandarajan (2002)
	Genetic Algorithm	Güvenir and Erel (1998)

The main idea of the judgemental techniques is to extract the sometimes-tacit knowledge held by managers. Such techniques are used to determine the criticality of a product (as in the VED technique) or to rank different characteristics using pair-wise comparisons in the AHP or TOPSIS technique (Technique for Order Preference by Similarity to Ideal Solution). The results from pair-wise comparisons can subsequently be used as inputs for mathematical models. For instance, the AHP technique used by Flores *et al.* (1992) starts with pair-wise comparisons of both the importance of the SKU characteristics and the performance of products in terms of these characteristics. These results are subsequently converted to numerical values to come to an overall score that integrates all these characteristics. Saaty (1980, 1994) provides a more detailed explanation of the AHP methodology.

Another way to process expert opinions is referred to as case-based distance modelling (Chen *et al.*, 2008). The idea is to calculate a product's distance to a predefined reference point (such as the largest volume and the highest criticality factor) for all important characteristics, leading to a classification with A, B and C categories. Even though there is a reasonable amount of modelling involved, the authors stress that the intuitive distance concept is easily understood by decision-makers.

A wide range of techniques can be found which rely on statistics. Some of these approaches classify SKUs on only one criterion whereas others incorporate a large number of characteristics. The traditional ABC approach and the related FSN/FNS approach are examples that mostly sort products on a single characteristic. In the FSN (Fast, Slow and Non-moving) and the FNS (Fast, Normal and Slow moving) techniques, demand volume in a period is used to determine the product class. In the traditional ABC approach, the demand volume is generally multiplied by the unit price and then sorting is based on the single criterion demand value. For the ABC approaches, a dataset gathered by Reid (1987) is often used as a benchmark to test and compare techniques (Flores *et al.*, 1992; Ramanathan, 2006; Ng, 2007; Zhou and Fan, 2007; Chen *et al.*, 2008).

Other statistical techniques use more than one characteristic. When considering a pair of characteristics, researchers use tables, matrices or graphical techniques to illustrate their classification. For instance, D'Alessandro and Baveja (2000) plot all products on a graph with mean weekly demand volume along one axis, and the associated coefficient of variance on the other. For each quadrant in the graph, a production strategy is determined. Syntetos *et al.* (2005) distinguish four quadrants based on the mean inter-demand interval and the squared coefficient of variation of the demand sizes (when demand occurs). The cut-off values for their quadrants are based on a comparison of theoretical MSEs (mean squared errors) of different forecasting methods

Another interesting technique is the decision tree. Here, the classification is performed in a stepwise fashion, one characteristic at a time. For instance, Porras and Dekker (2008) first look at the criticality of the product, then at the demand volume, and finally at price. For each combination, a specific inventory management procedure is developed. Kobbacy and Liang (1999) included statistical tests for each step in a decision tree to determine, for example, whether there is a trend (e.g. seasonality) in the demand pattern.

Finally, we found several more advanced statistical approaches for SKU classification that can easily deal with a large number of characteristics. Quite a number of authors present optimisation models to extend the basic ABC methodology by using multiple characteristics. For instance,

Ramanathan (2006) considers annual demand volume, unit cost, product criticality and product lead-time, and uses weighted linear programming to come to a classification. Zhou and Fan (2007) extend Ramanathan's methodology by comparing a SKUs most favourable and least favourable scores for the various SKU characteristics. Ng (2007) presents an alternative to Ramanathan's optimisation model. His paper also includes a simple mechanism for calculating the classification score in a spreadsheet package rather than in specialized optimization software. Stanford and Martin (2007) integrate inventory control rules and traditional ABC classes based on demand value characteristics to optimally determine the number of classes and the borders between classes. Essentially, they model the cost performance of an inventory system with a given set of product classes and, with the product class set-up as a decision variable, they minimise the integrated cost.

2.4.4 Context in which the SKU classification is used

There is a wide variety of industries in which SKU classification is used. Table 2.3 shows examples of petrochemical and pharmaceutical industries (process manufacturing), automotive and lighting industries (discrete manufacturing), as well as high tech and low-tech industries. The specific industry or context of the study was found to influence the choices made in the SKU classification. These contextual factors can be related to the product, the production process or the life cycle of the product. Güvenir and Erel (1998) provide a particular example of a specific characteristic related to the product. Their classification uses 'stockability of the product' since stocking explosive products for the mining industry is not always possible. D'Alessandro and Baveja (2000) provide an example from the process industry where an operational characteristic of the production process (typical emulsion batch size) is used to distinguish between SKU classes. Applying the same approach in another context (with different batch sizes) would lead to different SKU class borders. In addition to aspects on the product or process level influencing SKU classification, the product life cycle of a product can also influence the classification. Wu *et al.* (2006) give an example from the high-tech industry, where the typically short product lifecycle has a major influence on the demand pattern.

2.5 Discussion: The relation between the factors in a SKU classification

The previous section shows the great diversity in papers and approaches to classify SKUs. In this section, we aim to extend the literature on SKU

classification from the level of individual examples to the conceptual level by not only discussing the aspects presented in Section 2.4 but also their relationships.

The first observation that can be made from our study is that the aim of the classification, the characteristics, the technique, and the context are interrelated. Together they determine the specific SKU classification and therefore they should not be considered in isolation. The interrelatedness of the important aspects of a SKU classification is shown in a mind map (see Figure 2.2). Mind maps can be used for pre-analytic idea jostles (for more details see Eppler, 2006). Here, we sketch and use it as an intermediate step to explore the various relationships. In other words, it is a first step towards building a conceptual framework for SKU classification. Therefore in Sections 2.5.1 to 2.5.4 we discuss each element presented in the mind map and explore possible relations between the aspects. Based on the discussion, Section 2.5.5 presents the conceptual framework in which we summarize and visualise how the elements relate to each other.

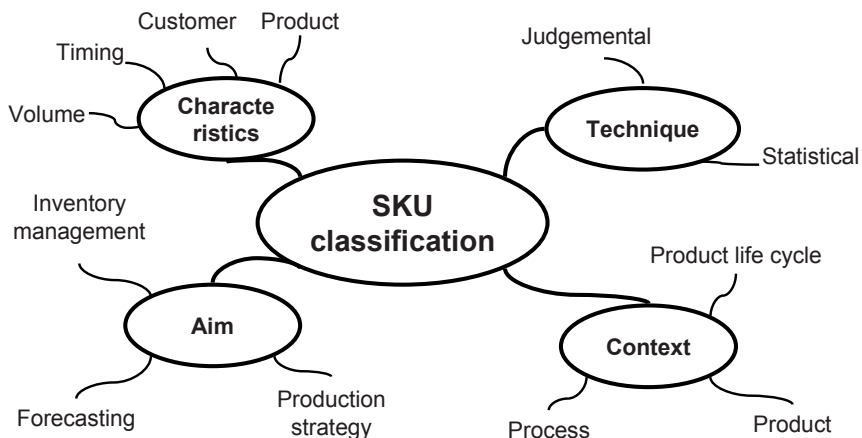


Figure 2.2: Mind map of SKU classification

2.5.1 Aim of the SKU classification

Classifying SKUs is often not an aim in itself. Most studies in the area of inventory management aim to reduce the money or the space tied up in inventories and therefore use *volume* and *product* characteristics (e.g. space needs or unit cost). Often, classifications are based on the multiplication of a *volume* and a *product* characteristic (as in the ABC approach). However, can this really result in the best outcome in all inventory management situations? We have three good reasons to believe that this is not always the case. Firstly, it is clear that inventory management for spare parts differs

from that for regular products (Kennedy *et al.* (2002) and Boylan and Syntetos (2008) describe these differences). The focus in managing spare parts inventories is generally less on the money value or space needs of the parts but more on the consequences non-availability of parts for the customer – especially when this could stop an entire production system. For this reason, studies on the management of spare parts inventories often use *customer* characteristics, such as customer criticality, rather than *product* characteristics. Secondly, a recent contribution by Teunter *et al.* (2010) challenges the fundamental approach of multiplying demand volume and cost characteristics. They argue that, in order to optimise inventory, product categories should be based on the demand volume divided by the unit holding costs rather than being multiplied by the unit cost (they also take shortage costs and order quantities into account). Their rationale is that a better overall delivery performance can be achieved at a lower overall holding cost when a relatively high delivery performance (through higher inventory levels) is achieved for products with a low holding cost. Thirdly, classifying individual products ignores possible relationships between products. Shipping to a customer might only be possible or sensible if all the products on an order are available. Another example of a relation between SKUs is the similarity of products. Production planning might depend on clustering products on recipe or packaging format to reduce set-up costs. In designing a SKU classification system for inventory management, such issues should be considered.

Studies that have their aim in the area of forecasting more often consider *timing* characteristics than studies in other areas. This is probably related to the fact that the selection of a forecasting method is influenced by the variability of the demand. Variability not only relates to the *volume* (e.g. demand size variability, demand lumpiness) but also to the *timing* of the orders (e.g. mean inter-demand interval, intermittence - see Williams, 1984; Eaves and Kingsman, 2004; Syntetos *et al.*, 2005).

Studies related to production strategy all use characteristics related to *volume*. The use of the total demand volume reflects the impact products have on the organisation. Fisher (1997) also stressed the differences in the predictability of demands for functional and innovative products as the driving force for different supply chain policies and practices.

Our synthesis of previous studies provides some evidence that studies with the same aim have characteristics that are commonly perceived to be appropriate to use. Therefore we argue that the selection of characteristics is influenced by the aim of the study. However, the fact that many studies include a certain characteristic does not necessarily mean that a characteristic should always be considered. Therefore, an interesting direction for further research is to further investigate how the aim

influences the characteristics used. One particular direction could be to study the use of criticality in classifications for inventory management of spare parts. Most studies use criticality but is the use of criticality always necessary for inventory management of spare parts? Or are there contingencies when this is not the case? Exploring this dependency would be an interesting topic.

2.5.2 Characteristics in a SKU classification

We observe that virtually all the studies (44 out of 45 studies in our sample) used a characteristic related to *volume* where the level of aggregation depends on the aim of the study (next to other factors such as data availability, periodic reviews, industry norms): ranging from individual orders to aggregation on a daily, weekly, monthly or annual basis. As noted previously, *product* characteristics such as unit price tend to be used in inventory management studies, and *timing* characteristics are mainly used in forecasting studies. Studies on spare parts often take *customer* characteristics (where the customer can be the production process), such as criticality, into account. Characteristics that are very specific for a setting are sometimes included. In our literature review, we found studies using ten characteristics, but we did not find clear arguments for the number of characteristics selected. Intuitively, one might expect a trade-off between the additional effort of acquiring more information on SKU characteristics and the gain in outcome quality. One avenue for further research would therefore be to investigate in which situations the use of a larger number of characteristics is beneficial. Particularly, we expect a difference in the number of characteristics used based on the level of automation in a production setting. In highly automated production settings we expect that SKU characteristics could be more easily retrieved due to lower costs of acquiring data which will result in a more refined classification based on a higher number of SKU characteristics.

2.5.3 SKU classification technique

The number of characteristics and the nature of the characteristics do influence technique selection. Some simple statistical approaches restrict the number of characteristics whereas, in general, the more complex statistical techniques can easily deal with a larger number of characteristics. The qualitative nature of some characteristics (e.g. criticality being defined as high, medium or low) can be used in some expert judgement approaches but cannot easily be used in mathematical approaches. In the latter, some authors explicitly exclude qualitative characteristics from their classification (e.g. Zhou and Fan, 2007; Ng, 2007), because qualitative characteristics are believed not to fit to the optimisation model. In selecting

a technique for a specific situation, one has to assess the additional benefits of techniques that require a significant amount of modelling or data collection over other, simpler, techniques. In further research one could try to come up with guidelines or rules of thumb to come to this decision.

2.5.4 Context of the SKU classification

Section 2.4.4 shows that one should carefully consider whether contextual factors should be incorporated in the SKU classification. Examples are given for when the context influences which characteristics are included in the classification and for when the operationalization of the classes is influenced by contextual settings. However, the importance of contextual factors in a number of studies does not mean that such factors are relevant in all situations. We observe a number of papers in which general demand classification techniques are presented (Chakravarty, 1981; Flores *et al.*, 1992; Huiskonen, 2001; Ramanathan, 2006; Zhou and Fan, 2007; Ng, 2007; Chen *et al.*, 2008). We also see a number of examples where identical ABC approaches are applied in different industries. This raises the question as to when the context, in which the SKUs are classified, is sufficiently different to warrant including contextual factors in the classification method. In other words, are some methods more general in their applicability than others? Investigating when it is desirable to include contextual factors is an interesting direction for further research. Guidance on which factors to include can possibly be found in literature that studied fundamental differences between industries (e.g. Taylor *et al.*, 1981), within industries (e.g. Fransoo and Rutten, 1994) or provided characteristics of a specific industry (e.g. Akkerman and Van Donk, 2009). A particular direction could for instance be to study the effect of sequence-dependent set-ups in the process industry. The set-up costs of a recipe in the process industry result in the clustering of demand for end products based on the recipe. Production intervals (e.g. cyclical plans or campaigns) of a recipe therefore influence the production interval of an end product. We therefore expect these set-up costs and the related production intervals to influence the SKU classification.

2.5.5 Conceptual framework

In all papers, classifying SKUs is about identifying a number of SKU classes and drawing borders between these classes. Together we call this the operationalization of SKU classes. Next to the decision how to operationalize the SKU classes, decisions are made which characteristics to include and which technique to use. These three interrelated decisions made are labelled together as the method. Figure 2.3 visualises the interrelationships.

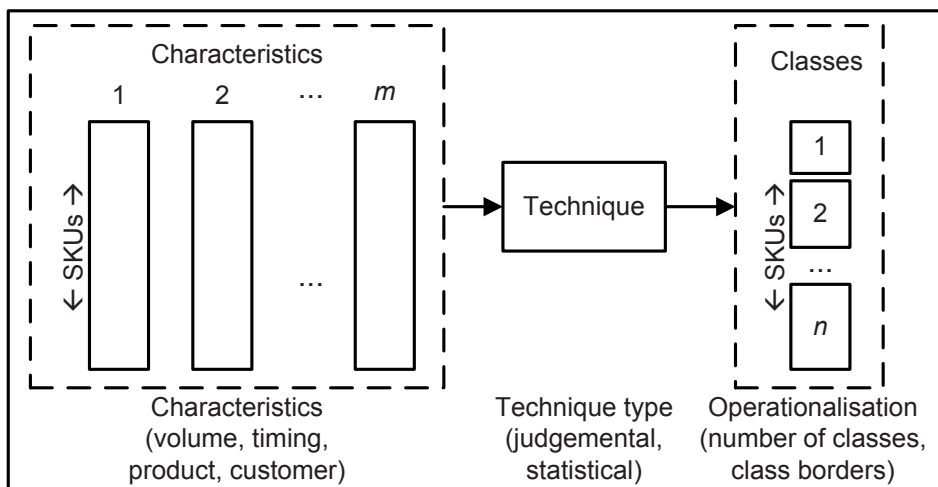


Figure 2.3: Coherence of decision steps in selecting an SKU classification method

Before we construct our conceptual model, we first discuss the operationalization of SKU classes, as the basic decisions on the number of classes and their borders are made in every classification. Here, we include possible relations to the aspects described in the previous sections.

The number of classes employed is usually between three and twelve (Stanford and Martin, 2007), but there is no guidance on how to determine the optimum. One could argue that some of the more popular techniques have three classes (e.g. ABC, FSN, VED) and in that situation the operationalization of the classes is influenced by the technique. However, examples exist where these techniques are used with more classes (for example, Sani and Kingsman (1997) discuss an ABC application using 11 classes).

Different methods exist to define class boundaries. In the ABC approach, one often defines class borders based on percentages of products (e.g. 10% of products are A, 40% B, and 50% C). Other methods use visual inspection of data, descriptive statistics (e.g. quartiles, median) or operational characteristics (e.g. batch size). Companies with similar aims and characteristics may well set different class borders in their SKU classification. Eaves and Kingsman (2004) confirm that idea by stating *“what is classed as a smooth demand pattern in military terms may well be considered intermittent in other industries”*. D'Alessandro and Baveja (2000) contend that the choice of boundaries between classes may not even have any intrinsic meaning.

The number of classes (Sani and Kingsman, 1997) and the boundaries between them (Eaves and Kingsman, 2004) are essentially management decisions. However, how can or should managers take such decisions, and what could be leading in such decisions? These questions and the many examples of ABC applications with different numbers of SKU classes, suggests an interesting direction for further research. Namely, whether it is only organisational or managerial considerations that influence the number of SKU classes and class boundaries, or whether there is some logic, which explains how companies decide on the number of SKU classes and class boundaries. We would expect a trade-off between performance and complexity. While the best performance could theoretically be expected to be achieved by creating different classes for each product this will come at the expense of complexity. On the other hand, using only one class will result in a relatively poor performance. Again, different approaches have been followed and presented in the literature, but little foundation is offered for individual choices. Further exploration of the number of classes used to balance between performance and complexity, thus seems another challenging area for further research.

At the start of the discussion section, four interrelated areas were mentioned: the aim of the classification, the technique, the characteristics, and the context. Together these areas influence the central classification decision of how the SKU classes are operationalized. Based on the previous sub-sections, we feel confident to further refine the nature of the relationships of the factors as follows:

1. The aim influences the characteristics chosen (see Sections 2.5.1 and 2.5.2).
2. The context influences the characteristics chosen (see Sections 2.5.2 and 2.5.4).
3. The characteristics chosen influence the technique (see Section 2.5.3).
4. The technique chosen influences the operationalization of the classes (see Section 2.5.5).
5. The context influences the operationalization of the classes (see Sections 2.5.4 and 2.5.5).

These five relations are graphically represented in Figure 2.4.

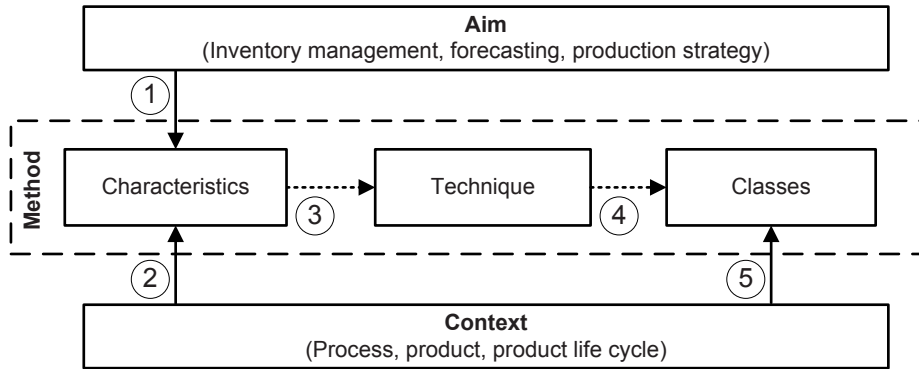


Figure 2.4: Conceptual framework for SKU classification

Two remarks need to be made regarding Figure 2.4. Firstly, the existence of a relationship between two areas does not mean that it influences the classification in all situations. For example, similar ABC classifications are used in different contextual settings. However, the relation indicates that the literature provides examples of studies in which these relationships exist and therefore should be considered. Secondly, the method of the SKU classification in Figure 2.4 might be influenced by the strategic aim of the company as well. A company that aims for high service levels might include more characteristics, select more labour/capital intensive classification methods or use other class borders than a company aiming at low costs. However, in the absence of guidance on the topic we would argue that the above conceptual framework is a good starting point for further research as well as for further specifying the various relationships.

2.6 Conclusions and future research

This paper provides a systematic analysis of the literature on SKU classification resulting in an overview of aims, techniques and characteristics used to classify SKUs in various contexts. By synthesising and structuring the existing studies in the field, the lack of guidance on how to classify SKUs became apparent leading to detecting several important unanswered questions.

In addition to reviewing previous work on SKU classification, this study contributes to the literature by (i) distinguishing four main characteristics used for SKU classification (*volume*, *timing*, *product* and *customer*), (ii) discussing the main factors influencing SKU classification (Figure 2.2), (iii) revealing three key decisions that are made in each SKU classification method (Figure 2.3) and (iv) proposing a conceptual framework for SKU classification (Figure 2.4). Managers in practice can benefit from our

findings as they provide an overview of studies conducted in a variety of industries. Managers in related industries can learn from these experiences. Furthermore, the paper highlights which decisions need to be taken to come to an appropriate SKU classification and as such offer practical guidance.

SKU classification is a widely applied concept in production and operations management that has, so far, received mainly context-specific and fragmented attention in the literature. As a consequence it is therefore difficult to assess and compare the performance of different approaches. The conceptual framework and the discussion in this paper contribute to the development of production and operations management theory on SKU classification by synthesizing previous work. This study provides the groundwork for theory building with respect to SKU classification. Related to the framework a number of directions for further research can be identified.

One of the main aspects to study is the dependency on context (e.g. Whetten, 1989). What makes a specific industry or company sufficiently different from others to require the inclusion of specific contextual factors in the SKU classification method? Our study has shown some examples where the classification characteristics are influenced by specific industry characteristics. To be able to assess the performance of classification methods, context-specific factors need to be taken into account. Guidance for how to include such specific factors can possibly be found in literature that studied fundamental differences between industries (e.g. Taylor *et al.*, 1981), within industries (e.g. Fransoo and Rutten, 1994) or provided examples from a specific industry (e.g. Akkerman and Van Donk, 2009). A particular direction could be to study the inclusion of set-up costs and the related cyclical production plans in process industries as the production interval on a recipe level influences the production interval on a SKU level. Additionally, a broader survey or case study research over a range of companies might reveal which and to what extent contextual factors should be taken into account when classifying SKUs, and if and how performance is influenced.

Another direction for further research is to identify how the aim of the study influences the selected characteristics. This study provides a number of examples of commonly used characteristics in studies with a common aim (e.g. the use of criticality for inventory management of spare parts). But is the use of criticality always necessary for inventory management of spare parts? Or are there contingencies when this is not the case? Exploring the dependency of the chosen characteristics on the aim of the study is an interesting direction for research. A possibility would be to conduct a review or a multiple case study on this topic. Evaluating the performance of

a number of classifications with and without certain characteristics might provide such insight.

Some more specific directions for further research related to the classification method can also be identified. We have observed that recent contributions have applied new techniques such as distance modelling and neural networks in developing SKU classes. More studies are needed to clarify when such techniques, which require a reasonable amount of modelling, are preferable over other, simpler techniques. Comparing the performance of a range of classification techniques and the efforts needed to apply these techniques on a number of datasets might provide such insights. Similar directions for future research would be to evaluate the decisions on the number of characteristics, the number of classes and class borders. We expect the level of automation to influence the data collection efforts and therefore the decision on the number of characteristics. Further, we expect the use of the classification technique to influence the number of classes. Having a large number of classes could be useful in a highly automated production setting where it might be difficult to handle in a low automated production setting due to human limitations.

This paper is a first step to unravel whether some deeper logic can be found to explain how the different SKU classification decisions are made or should be made. Ultimately the aim for further research would be to construct a decision framework on how to determine an appropriate SKU classification.

3. Reasons for updating SKU classifications: The production strategy classification in a dairy company²

Abstract

Classification of SKUs (stock keeping units) is a much-used approach to determine production strategy. However, the literature mainly provides approaches for determining categories at a certain moment in time without addressing the need and factors that urge revision of a determined classification. This paper addresses that gap. The empirical part relies on an extensive case study of a dairy company and uses a large longitudinal data set from the case company. Our study demonstrates that periodic reclassification is needed to either increase the competitive strength of the company or to reduce risks. Still, classification and reclassification are much more a subtle process that balances customer wishes, operational decisions and commercial motives than a straightforward calculation.

3.1 Introduction

Companies struggle with determining whether production for certain products should be based on the make-to-order (MTO) policy or that the make-to-stock policy (MTS) is better. Often, the sales department prefers a MTS strategy for all SKUs in order to respond quickly to changing market demands. Contrary, the financial department prefers the MTO strategy to avoid the risks of obsolete products by producing to stock. Contrasting market, product, and production characteristics cause the production strategy decision to be surrounded with discussion and opposing interpretations. In the presence of these opposing needs the question remains how to select the appropriate classification for all SKUs. Moreover, a second question relates to the validity of a classification; how long is the classification valid and what causes that a classification should be adapted?

This paper studies how the production strategy classification is determined and adapted for SKUs in the food processing industry. Studying this decision in the food processing industry is relevant as the demand for

² An earlier version of this chapter is published as Van Kampen, T.J. and D.P. Van Donk (2011), Dynamics of SKU classification: the production strategy in a dairy company, proceedings of the 18th Annual EurOMA Conference, Cambridge, United Kingdom.

products is volatile, the products have a limited shelf life and competition is high and increasing. As price is still a dominant factor in the food processing industry, properly determining and adapting the production strategy for SKUs is important to keep the cost low as poor classifications could result in lost sales, penalties or the waste of products.

According to Olhager (2003) a production strategy decision is mainly affected by the demand volatility and the ratio between delivery and production lead-time. However, for particular industries other aspects affect this decision as well. Van Donk (2001) provides examples from the food processing industry illustrating that particular food processing characteristics (e.g. expensive set-ups and high risk of obsolescence) influence whether SKUs should be produced to order or to stock. Olhager (2003) and Van Donk (2001) both summarize characteristics that influence the production strategy for individual products. However, which production strategy to choose at different levels of these - sometimes conflicting - characteristics is unclear. Managers responsible for a wide range of SKUs therefore lack guidance on how to classify their products into categories.

Recently, Van Kampen *et al.* (2012) reviewed the fragmented classification literature and propose a framework to classify SKUs. Their paper provides insight in which characteristics are used in various circumstances. However, Van Kampen *et al.* and the 45 papers reviewed therein hardly pay attention to the dynamics of a classification used (e.g. when and how to adapt a classification). SKU classifications are mostly presented as snapshots at a certain moment in time. So far, the literature has barely discussed if and how often the classification should be revised and which factors affect the timing of such a revision. As the characteristics on which a classification is based fluctuate (e.g. demand volume, forecast accuracy), we argue that a classification needs to be reviewed over time.

The aim of the paper is twofold. Firstly, we investigate how characteristics of the food processing industry affect the production strategy classification. Secondly, our aim is to go beyond understanding the logic of a classification at one moment in time by investigating how the production strategy classification should be adapted over time. Given that little is known on how to adapt a classification over time we choose for an explorative research design. A case study approach is used to in-depth explore the factors affecting the classification and reclassification of SKUs on production strategy in a dairy company.

The paper is structured as follows. The following section reviews related literature after which we present our approach. Subsequently we introduce the classification in use and how it is adapted over time. In the last part of the paper we discuss the outcomes, draw conclusions and make suggestions for further research.

3.2 Theoretical background

This section discusses key findings in the production strategy literature followed by more details of the literature on production strategy in the food processing industry. Subsequently, it presents the classification framework of Van Kampen *et al.* (2012) and provides possible causes for adapting a classification over time.

3.2.1 Production strategy

Olhager (2003) distinguished between make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and engineer-to-order (ETO) production strategies. The difference between the strategies relates to the stage in the manufacturing value chain, where a particular product is linked to a customer order (Customer Order Decoupling Point (CODP), Hoekstra and Romme, 1992, also labelled as the order penetration point (OPP)). The positioning of the OPP for the production strategies is visualized in Figure 3.1.

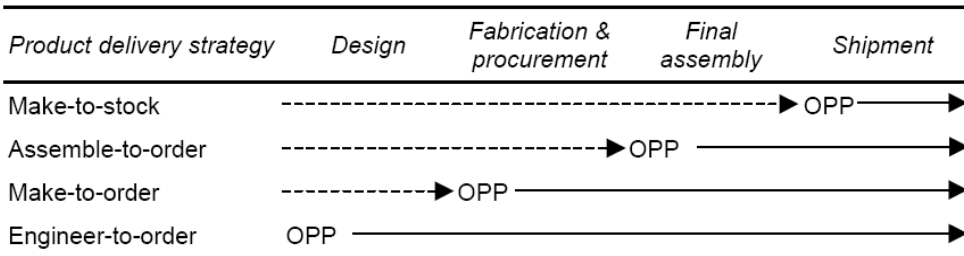


Figure 3.1: Order penetration points (adapted from Olhager, 2003)

Given that quite a number of authors already studied the OPP and the related production strategy classification, we only summarize the key findings in the area. According to Olhager (2003) two major factors can be identified that affect the strategic positioning of the OPP and therewith the production strategy. These are the production to delivery lead-time ratio (P/D ratio) and the relative demand volatility (RDV). The RDV is defined as the coefficient of variation, i.e. the standard deviation of demand relative to the average demand. Contrary, Fisher (1997) argues that determining the best supply chain for a product is largely based on a single criterion namely demand predictability. His idea is to use a physically efficient, lean, make-to-stock supply chain for predictable demand, whereas unpredictable demand should be handled within a market-responsive, agile, make-to-order supply

chain. On the other hand, Wanke and Zinn (2004) empirically studied which factors are predominantly affecting the choice of production strategy. They collected SKU information for 'A products' (top 20% in sales volumes) and 'C products' (bottom 5% in sales volumes) in 181 production companies. They found that the delivery time in days and the coefficient of variation of sales volumes are the most important factors influencing the production strategy decision.

Recently, Perona *et al.* (2009) compared 11 papers which address the issue of OPP decisions (they name it decoupling point decisions) and therewith the related production strategy decisions. They state that decoupling point decisions have not been adequately addressed in the available literature, and that the known theoretical approaches have limitations. Analytical approaches use rational and quantitative models, but their complexity does not seem suited to easily be implemented in practice. As a result there is a scarcity of practical applications of structured approaches (Perona *et al.*, 2009). The need for more empirical studies on this topic was also put forward by Soman *et al.* (2004) who reviewed combined MTO and MTS production strategies.

In summary, we notice that the papers of Fisher (1997), Olhager (2003), and Wanke and Zinn (2004) stress the use of a measure regarding the variability or predictability of the volume in the production strategy classification, where two of the three papers argue that delivery time is important. Moreover, Perona *et al.* (2009) and Soman *et al.* (2004) stress the need to study production strategy classification from a practical point of view.

3.2.2 Production strategy in food processing companies

Figure 3.1 shows four production strategy alternatives (MTS, ATO, MTO and ETO). However, not all the alternatives are relevant in food. The ETO strategy is uncommon in food as it is only applied in companies supplying high value, customized products, with deep and complex product structure (Hicks *et al.*, 2000). ATO strategies industries are rare in food due to the facts that intermediate products are mostly perishable and storage possibilities are limited (Soman *et al.*, 2004). Therefore in food processing industries it is common to have the MTS and the MTO strategy as most likely alternatives (e.g. Van Donk, 2001; Soman *et al.*, 2004).

Traditionally, food processing companies were producing on a MTS base until the high product variety and the variability in market demand forced the companies towards MTO production. However, producing only to order is not a sensible alternative due to the high set-up costs and capacity investments which are needed to deal with the fluctuating demand. In order to keep utilization of the production capacity high, the companies move

from only MTS production towards a combined MTO/MTS production (Soman *et al.*, 2004). An advantage of the combined MTO/MTS production is that MTS products can be used to fill capacity in periods of low demand by which production costs are kept low. A challenge in combined MTO/MTS production is to decide which products should be made to order and which made to stock as wrong classifications could result in lost sales, penalties or obsolete stocks (Soman *et al.*, 2004).

A number of authors (e.g. Van Donk, 2001; Soman *et al.*, 2004) argue that particular food processing characteristics (Table 3.1) influence whether SKUs should be produced to order or to stock. For example, expensive set-ups result in more MTS production whereas a high risk of obsolescence results in more MTO production. However, which production strategy to choose at different levels of these - sometimes conflicting - characteristics is unclear. Therefore it is not a surprise that Van Donk (2001) brings forward that more cases are needed in the food processing industry to explore the decision logic for the - overall - production strategy.

Table 3.1 - Overview of food production system characteristics (Soman *et al.*, 2004)

Plant characteristics	Product characteristics	Production process characteristics
-Expensive capacity with flow shop oriented design -Extensive sequence-dependent set-up and cleaning times	-Variation in supply and quality of raw material -Limited shelf life for raw materials, semi- finished and finished products -Volume or weight as the unit of measure	-Variable yield and processing time - Divergent flow structure - Multiple recipes for a product - Packaging stage labour intensive, processing stage not - Production rate mainly determined by the capacity

3.2.3 A framework for SKU classification

Syntetos *et al.* (2009) argue that classification has not received sufficient academic attention given its implications. Until recently, no structured approach existed to classify SKUs as most approaches are based on managerial insights in a particular production setting sometimes combined with insight from academia. Recently, Van Kampen *et al.* (2012) reviewed the SKU classification literature in the production and operations management field. As a result they present a generic framework to structure SKU classifications (Figure 3.2) and guidance on decision making processes in designing classifications. Five main factors are identified (aim, context, characteristics, technique and operationalization of classes) which together shape a classification. The aim and the context are the basis for the classification as they provide the goal of the classification and circumstantial settings (including limitations) in which the classification has to be constructed. Both the aim and the context guide which characteristics

need to be included in the classification method. The relevance of specific characteristics affects the selection of possible techniques. For example, most mathematical techniques cannot deal with qualitative characteristics. We refer to Table 2.4 in the previous chapter for a summary of techniques used to classify SKUs. The final aspect of a classification is to operationalize SKU classes. Decisions need to be made on the number of classes and the class borders. Contextual factors (e.g. batch sizes) offer a natural way or constraint to determine class borders. The framework by Van Kampen *et al.* (2012) provides a basis to understand the decisions that are made in classification approaches. It is mainly derived as a summary and synthesis of the literature in the area, but might also be used to guide managerial decision-making. However, the usefulness of the framework in a managerial context is not yet explored. Therefore it is unclear what its practical value is. In the present paper we use the framework to discuss and report on the production strategy classification approach in the case study and therewith try to understand the value of the framework from a practical, managerial point of view.

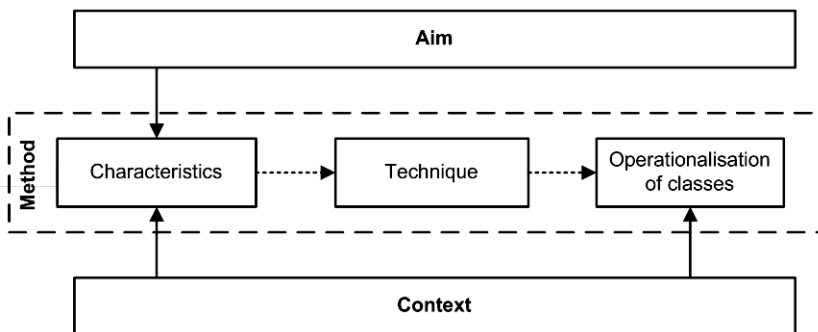


Figure 3.2: SKU classification framework adapted from Van Kampen *et al.* (2012)

3.2.4 The value of a classification over time

Characteristics, on which a classification is based (e.g. the demand volume), are usually not fixed but vary over time. However, nearly all SKU classifications described in the literature, use data at one, single moment in time. Therefore, a gap in theory on SKU classification is that the dynamic nature of a classification in use is largely ignored. The relevance of revising a classification increases if characteristics are included which can be expected to change over time. An example of such a characteristic is the product life cycle. The stage in the product life cycle affects the preferred production and inventory policy (e.g. Aitken *et al.*, 2003; Wu *et al.*, 2006). For some products a fast response by either spare capacity or high

inventory levels could be desirable in the introduction stage to avoid stock outs. Other examples of such changing characteristics are the presence of seasonal patterns or trends (e.g. Olhager, 2003; Kobbacy and Liang, 1999). Olhager shows that a company may choose to manufacture some products to stock (MTS) in periods with low demand and shift to MTO or ATO in anticipation of peak demand. The above-mentioned authors all stress the need to adapt a classification over time but fail to do provide a structure for reclassification. One exception is Aitken *et al.* (2003) but they only provide a rough estimate of the timing when classifications need to be adapted.

The arguments above clarify that changes in product life cycle, seasonal patterns or other characteristics should result in reconsidering and probably adaptation of an existing classification. However, SKU classification papers hardly provide any guidance how a classification should be updated and which factors need to be considered to decide on a revision of the classification. As a result, most SKU classifications are arbitrary snapshots, primarily based on the moment in time when a classification is performed.

Given the gaps identified in the review of the literature our paper has the following aims:

- (1) To understand how conflicting characteristics of the food processing industry affect the production strategy classification.
- (2) To explore the need to adapt a classification over time.

3.3 Approach

In this paper we use a case study approach to understand how SKUs are classified on production strategy in the food processing industry and to study the dynamic nature of the classification. We selected the case study approach as it allows us to study a phenomenon in its real life context (Yin, 2003). As still little is known on both the practical usefulness of the Van Kampen (2012) guidelines to structure a production strategy classification and the process of reclassification, a single case study approach is used. For the case study we selected a dairy company that was representative for the food processing industry (the “typical case”, cf. Yin, 2003). Table 3.1 in the literature section describes the distinctive characteristics of the food processing industry. Not all these characteristics are present in all food processing companies, but at the selected dairy processing company all of these characteristics are present. Moreover, one of the advantages of selecting a company from the food processing industry is that we can relate our outcomes to general production strategy findings (e.g. Olhager, 2003) as well as to industry specific findings (e.g. Van Donk, 2001).

The case company is a dairy processing plant that supplies products to more than 20 countries on four continents either through regional sales organizations or through direct deliveries to customers. To meet the customers' demand, a number of base components (mainly full cream milk and skimmed milk) are mixed and processed into more than 100 recipes. Out of the recipes over 700 products are produced on 18 packaging lines differing in packaging format (e.g. cups, cans, cartons, bulk containers) and size (ranging from 7g to 900 kg). The production process is a two-stage production process consisting of a processing phase and a packaging phase. In the processing phase there is a strong focus on producing large batches where there are limitations regarding minimal batch sizes due to technological reasons. The packaging phase is more flexible, of course large batches are preferred as well but smaller set-up times and fewer limitations make it possible to pack relative small quantities (e.g. less than one hour production).

The challenge in the company is to balance the conversion costs (e.g. labour and set-ups) and the storage costs (e.g. space and shelf-life) while the order lead-time (in this paper we define order lead-time as the period between ordering and shipping a product) meets the customers' needs. Set-up costs could be minimized by producing in large batches but can result in high storage costs especially if products are thrown away when they are stored too long (customers normally require about two third of the total commercial shelf life). As a result, production to order is preferred for unpredictable products (high risk of obsolescence) where production to stock is preferred for predictable products (low risk of obsolescence). The order lead-time of the products varies between two days and two months. The lead-time difference is caused by the combination of the time needed for producing the goods after the orders have arrived (mainly the difference between MTO and MTS) and the time needed to arrange transport to ship the product to the customer. The time to arrange transport (2-14 days) depends on the customers desire to ship the product by boat or by truck. The shipment time can be seen as more or less fixed as the geographical location largely determines what the appropriate way of transport is. Contrary, the part of the order lead-time related to producing the SKU after the order arrived is not fixed as it depends on the production strategy chosen by the company (e.g. MTO or MTS).

To study the production strategy decision in the case company an interview protocol was constructed to guide the semi-structured interviews. The protocol indicated the subjects that would be covered and the questions to be asked to the informants (Appendix 1 provides further details). The aim of the interviews was to understand how the company classifies and reclassifies SKUs on production strategy. We chose to ask the

questions to multiple respondents to increase the reliability of the outcomes and to allow for triangulation. The interviews were held with the logistical manager, demand planner and master production scheduler, who together are responsible for the process of selecting and approving the classification. The interviews were combined with other sources (content analysis of documents and product data) and insight obtained through a longitudinal participative study that one of the authors did in this company. These other sources next to the interviews allowed for understanding classification issues on a deep level and to further triangulate our findings. The interviews typically lasted one hour and the transcripts were sent back to the interviewees to further validate findings and to verify interpretation. If necessary, additional questions were asked for clarification. After the round of interviews a meeting was organised with all the interviewees in which we presented and discussed our observations on the classification and reclassification process. In the meeting also differences in views were discussed resulting in a convergence of views on the classification process. Next to the interviews, demand and forecast data was collected over a period of two years (2009 and 2010). The quantitative data made it possible to study how robust a classification is over time or whether there is a strong need to adapt a classification. The analysis facilitates that the dynamic nature of the classification could be observed (Section 3.4.2 provides more details on the analysis). The outcomes of the interviews, clarifications and discussions were coded on the five factors of the Van Kampen framework (Figure 3.2) where, given the aim of our study, reclassification was added as an additional coding factor. In Section 3.4 we present the converged findings.

3.4 Findings

In this section we discuss how decisions on production strategy are made and adapted in the case company. The factors of the Van Kampen framework are used to structure the classification approach.

3.4.1 The SKU classification in the case company

Aim of the classification

The aim of the classification in the case company is to select the appropriate production strategy by which the customer demand is balanced with the risk of obsolete stock. Soman *et al.* (2004) put forward that MTS used to be the default classification in food, which often is the preferred classification from the customer as well. However, the company has sound reasons not to grant the customer's wishes in all circumstances as the interviews revealed

a number of risks for the company. The risks that were mentioned are: risk that the customer does not pay, risk that stocks become obsolete if orders for MTS products are not received in time, and the risk that ingredients pass their shelf life if orders are not received in time. Therefore characteristics are included in the classification that take these three risks into account.

Context of the classification

The case company is a food processing company where the production process can be characterised as batch production. Therefore producing relatively small quantities in the processing phase is not possible (the minimal processing batch for recipes in the case is 20.000kg; packaging can be done in smaller quantities). Cyclical production plans are used to group the demand for end products on recipe in order to meet the minimal batch size. The minimal processing batch size and the cyclical production plan are typical contextual characteristic of the food processing industry and affect the SKU classification. The size of the minimal batch could be a measure to determine class borders as it is a strict constraint for production. Another contextual characteristic that affects the classification is the limited shelf life of dairy products. As a result of the shelf life, products cannot be kept to stock for a long period and have to be sold while the customer still accepts the remaining shelf life. Therefore, important contextual characteristics in the case are the risk that a product becomes obsolete due to the limited shelf life, the cyclical production plan and the minimal batch size.

Characteristics

The sections on the aim and the context show characteristics that need to be included in the classification. The characteristics that were identified are payment reliability, risk of obsolete stocks (shelf life) or obsolete components, cyclical production plan and minimal batch size. The company operationalizes the characteristics such that they can be measured and used in the classification.

- Payment reliability is operationalized as whether the customer has met the payments in the past.
- The risk of obsolete stocks or components relates to the accuracy of the forecast. The rationale is that the risk of producing stocks that become obsolete is low for products of which the forecast is accurate. The interviews revealed that the company operationalized the forecast accuracy of a SKU as the ratio between the forecast of a month (which was provided two months earlier) and the actual orders in a month.
- The use of the cyclical production plan is operationalized as the minimum production interval that a product currently has. The

SKU classification in a dairy company

cyclical production plan prescribes minimal intervals of one (regular recipes), two or four weeks (less regular recipes) for the different recipes.

- The batch size limitation is operationalized as the minimal batch size of a recipe. The minimal batch depends on the machine capabilities and the components used (e.g. the volumes of some recipes depend on the ingredients used). Smaller volumes cannot be produced and therefore this dimension is a prerequisite for guaranteeing the order lead-time.

Technique

The case company uses a decision tree approach as technique to classify SKUs on production strategy. Rationales why the company uses the approach are that (1) the technique is objective (2) it provides the possibility that the four above-mentioned characteristics are included and (3) the approach is easily understandable. The decision tree technique suggests a hierarchical structure in which production strategy decisions are made. Through the interviews a hierarchy could be identified that links the four dimensions (the hierarchy was not documented and made more explicit through the course of the research project). The primary dimensions are payment reliability (needs to be guaranteed for MTS) and forecast accuracy (needs to be high for MTS) these two dimensions determine whether a product is classified as MTO or MTS. Secondary dimensions are the minimal production interval (affects the lead-time for MTO) and whether an order for a product is sufficiently large for independently producing a batch of the recipe (guarantees the lead-time). Products that have a large order quantity and normally meet the minimal batch size are labelled as *Master*. Other products that do not meet the minimal batch size are labelled as *Slave*. In practice the difference between Masters and Slaves is that the delivery lead-time for Masters is guaranteed while the order lead-time of Slaves depends on other orders of the same recipe due to the fact that multiple orders need to be combined in order to meet the minimal production batch.

Classes

Production strategy classes are distinguished based on differences in expected order lead-time. A number of decisions on drawing borders between the classes are rather straightforward. The payment is either reliable or not, the minimal batch size depends on the processor (or sometimes on the ingredients used) where the production interval in the cyclical production plan depends on the recipe of the product. Contrary, the needed forecast accuracy is perceived to be quite difficult to determine. In

the company a deviation of less than 20% (forecasted volume vs. ordered volume) is seen as accurate and therefore this percentage is used as a cut-off value between the classes. Note that no further differentiation is made based on individual characteristics of SKUs as the percentage is used for all SKUs. Figure 3.3 summarizes the findings on the five factors of the classification framework.

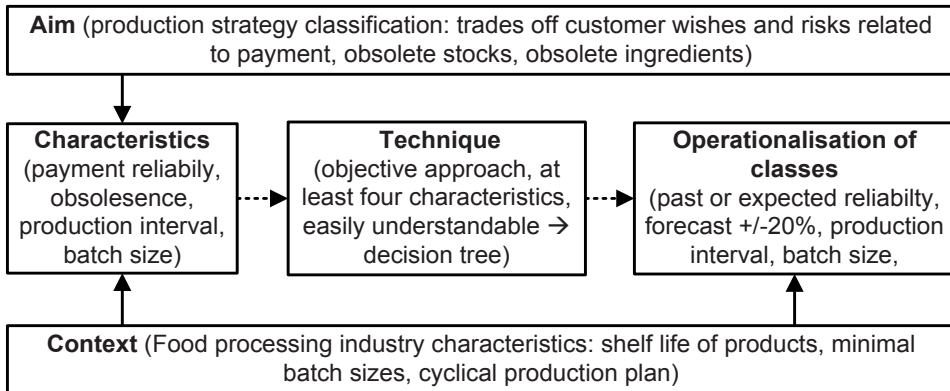


Figure 3.3: Summary of findings on the five classification factors

Classification structure

Figure 3.3 shows the main factors of the classification scheme in the dairy company. However, it does not provide the sequence how production strategy classifications are made. The classification sequences, logic and outcomes are visualised in Figure 3.4. The order lead-time of MTO products differs a lot from MTS products as MTO products are only planned after an order has arrived. Within MTO the regularity of the recipe further differentiates the lead-time. Finally, Masters differ from Slaves as they can be planned independent of other orders and therewith have a guaranteed lead-time.

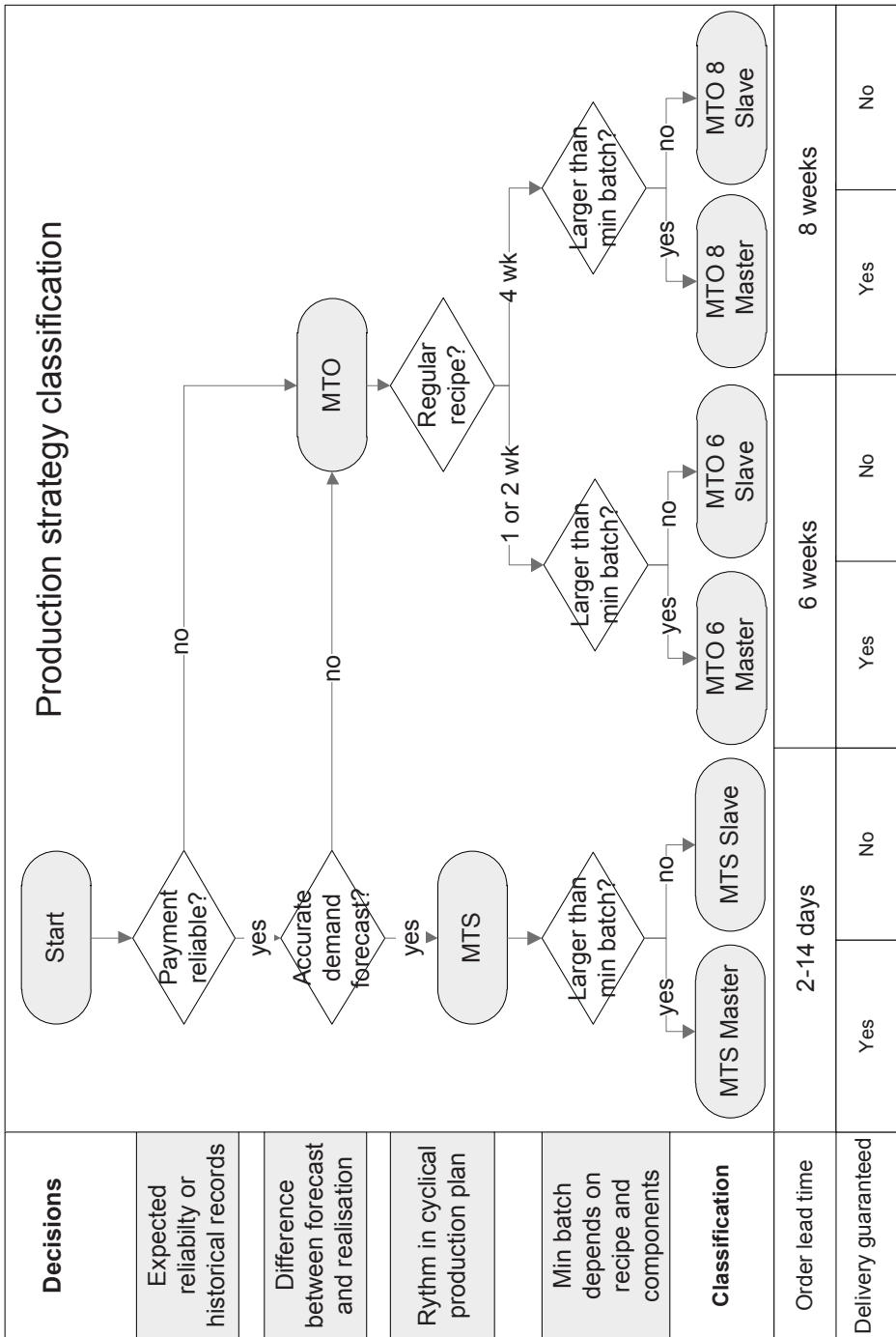


Figure 3.4: Production strategy classification procedure

3.4.2 Classification over time

The next step of the paper is to study the need for adapting SKU classifications over time. Product and demand data is analysed to determine how SKUs classifications change over time. Moreover, qualitative insight is provided on reasons for changing the classification.

Quantitative analysis on classifications over time

Historical data on the classification of SKUs could not be retrieved. However, product and demand data was available for retrospectively determining the classification for the different SKUs. By retrospectively determining SKU classifications we could study how robust the classifications are over time (e.g. whether different time intervals result in the same classification for a SKU). For this purpose, product and demand data was collected (data either provided by the demand planner or subtracted from the ERP system) of two consecutive years (2009 and 2010) for the two dominant packaging departments of the company. These departments produce around 250 SKUs and are responsible for 85% of the production volume in the factory. The approach of Figure 3.4 was used to classify the SKUs. The dimensions payment reliability and production cycle were not used, as they were more or less constant during the observed period. Therefore, we focus on demand volumes and the forecast accuracy of the SKUs.

Based on the interviews we knew that demand volumes vary over time. However, we were not sure what an appropriate time interval was to evaluate the classification. Therefore we selected three different time intervals (1, 3 and 6 months) to evaluate the classifications. Product and demand data was available on two consecutive years, which resulted in 24 monthly, 8 quarterly and 4 half yearly classifications for each SKU. For the three intervals we compared the successive classifications.

The percentage of changes in the SKU classifications (different from the previous period) is between 26 and 38 per cent depending on the selected time interval (Table 3.2). On both the MTO/MTS dimension and the Master/Slave dimension we see a large amount of changes. This implies that the classification for quite some SKUs changes over time if we would directly follow these results. However, the question remains what the benefits are of using the new classification. The interviews revealed that changing from a Slave to a Master (7-13%) or from MTO to MTS (8-14%) widens the ordering possibilities for the customer (e.g. the possibility to place an order at a later date) and is seen an improvement in customer service. Contrary, changing from a Master to a Slave (5-7%) or from MTS to MTO (8-12%) limits the ordering possibilities for the customer and is seen as deterioration of customer service. However, maintaining the old

classification in the last situation is undesirable from the company's perspective as it could result in excess and obsolete stocks.

Table 3.2 – Reclassifications over time

Interval	1 month	3 months	6 months
Modified classifications*	1376 (26%)	526 (32%)	273 (38%)
From Master to Slave	356 (7%)	91 (5%)	41 (6%)
From Slave to Master	360 (7%)	142 (9%)	91 (13%)
From MTO to MTS	441 (8%)	191 (11%)	99 (14%)
From MTS to MTO	413 (8%)	185 (11%)	84 (12%)

* The total number of reclassifications is lower than the sum of the individual reclassifications as a reclassification can be on both the MTO/MTS dimension and the Master/Slave dimension.

Table 3.2 shows that a high percentage of modifications occur in the classifications. Modifying the classification too often is not desirable from a marketing and customer point of view. Moreover, every adaptation causes an amount of workload to adapt and communicate the new classification. As a result, the company is cautious in making changes in the classification. The interviews further revealed that it is not perceived as fair that one mistake (a single inaccurate forecast) should be punished with a less favourable classification or that a lucky shot (a single accurate forecast) should be rewarded with a favourable classification. Therefore the company also weights the information of the previous periods to make the classification more robust (and thereby reduces the number of reclassifications). In data analysis we therefore included the data of the two preceding periods in the decision on the classification. The decision was made based on the rule that the most frequently occurring classification is used. For example, if a product was produced on the MTO base in period 1 and period 2 it will remain MTO even when the data of period 3 indicates MTS. However, if the data of period 4 indicates MTS as well then the classification is adapted to MTS in period 4. Figure 3.5 shows the difference between classifications based on 1 period (left part) or based on the inclusion of the data from the two preceding periods (right part). A difference between both sides of the figure is that changes in the classification on the 3 periods interval do not occur when the change is only an incident (e.g. the change from Slave to Master in period 13). Moreover, as a consequence of basing the classification on three periods, persistent changes have a time lag of one period (e.g. MTO changes to MTS in period 5 instead of period 4). The outcome of the smoothening procedure was that the number of reclassifications was nearly halved ranging from 13-23% of reclassifications in the smoothened scheme (Table 3.3). However, the high

percentage still stresses the need to adapt the classification over time due to changes in the demanded volume (Master/Slave) or changes in the forecast accuracy (MTO/MTS).

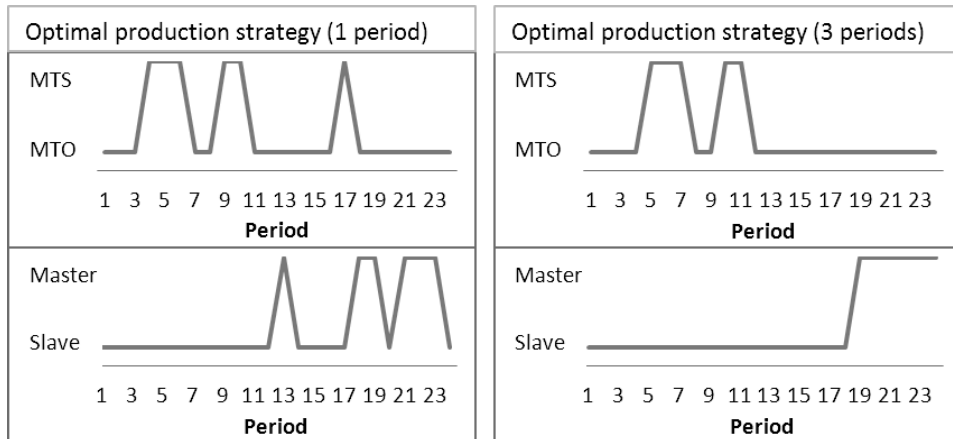


Figure 3.5: Example of a classification of a product based on one and three periods

Table 3.3 – Reclassifications over time (smoothened)

Interval	1 month	3 months	6 months
Modified classifications*	696 (13%)	226 (14%)	165 (23%)
From Master to Slave	132 (2%)	31 (2%)	27 (4%)
From Slave to Master	175 (3%)	68 (4%)	53 (7%)
From MTO to MTS	234 (4%)	70 (4%)	67 (9%)
From MTS to MTO	198 (4%)	71 (4%)	46 (6%)

* The total number of reclassifications is lower than the sum of the individual reclassifications as a reclassification can be on both the MTO/MTS dimension and the Master/Slave dimension.

Qualitative insight on classifications over time

Opposing the strict procedure, the interviews provided a number of examples where the SKU classification in use differed from the outcome of the production strategy classification procedure (Figure 3.4). Firstly, for some products it is known in advance that the demand will change and therefore it makes sense for the company not to base the classification only on the past orders for a product. Examples are product introductions and product phase-outs where pro-active decision making regarding the production strategy is required. Whether new SKU could be produced to stock in the company depends on whether the SKU replaces a previous SKU (if the previous SKU was produced on a MTS base than the new SKU could

qualify for a MTS as well) and whether the market was judged as a reliable market (a new product introduction in unreliable markets is only allowed on a MTO base). A second exception from the statistically determined classification relates to agreements on a customer level. Some customers require that all products can be ordered using the same short order lead-time and therefore should all be produced in the MTS regime. This circumstance often results in a renegotiation of the responsibilities between the case company and the customer. When the customer is willing to accept the risk of the forecasted volume of the coming two or three months than producing the SKU to stock is acceptable for the company for reliable customers.

Making exceptions from the systematically determined Slave classification could result in problems as the decision directly relates to unchangeable characteristics of the production process. At the same time the interviews revealed that some Slave products 'behaved' just like Master products, as they were not limited in their production interval by the minimal batch size. Moreover, the interviews also highlighted the need to properly communicate regarding the implications of the Master or Slave classification. We explain these observations by an example. One of the SKUs of the company was a low volume Slave product, which regularly could be produced right after a large volume SKU with the same recipe. Towards the customer nothing was communicated regarding the implications of the SKU being a Slave. At a moment in time, troubles arose. Another customer changed the recipe of a Master SKU. Subsequently, the production frequency of the recipe, which used to be shared with the SKU with the low volume, was reduced. As a result, the customer of the SKU with the low volume was confronted with two undesirable alternatives: either to change the recipe as well or to start ordering in larger quantities to meet the minimal batch size. Thoroughly communicating about the different classes and the underlying product and production characteristics at the beginning of the relation between the customer and the company could have avoided a lot of troubles, confusion and discussion.

3.5 Discussion

This paper addresses the classification and reclassification of SKUs in the context of the food processing industry. Contextual characteristics did affect the classification structure where the high number of variations stresses the need for reclassification. Below we discuss the most remarkable results of the study. The discussion on the classification of SKUs is structured by subsequently elaborating on the characteristics used, the process of determining a classification and the usefulness of the classification

framework. The discussion on reclassification is structured by discussing the various arguments in favour of and against reclassification and the proper time interval for reclassification.

3.5.1 The production strategy classification

The use of forecast accuracy in the SKU classification contrasts the findings of Olhager (2003) and Wanke and Zinn (2004). These authors include *variability* in the volumes to decide on the production strategy decision where we found that the *accuracy* of the forecast is important. In other words, demand fluctuations do not result in excess stock as long as they are properly forecasted. Our finding fits into the argument of Fisher (1997) who argues that demand predictability largely determines what the best supply chain strategy is for a product (MTO or MTS). As highly variable demand is often difficult to forecast, we expect a high correlation between variability in volume and forecast accuracy. Yet, we perceive that in general forecast accuracy is a more precise measure to choose between MTO and MTS.

A clear contribution is payment reliability as an important classification characteristic that is not yet considered in the literature (see Van Kampen *et al.*, 2012, Table 3.3). However, the dimension seems crucial for many companies supplying to unreliable markets where bank guarantees are needed to assure payments. Producing in advance of the guarantees could result in high inventory holding costs or even waste of products.

Contrasting most classification papers presenting a strict classification structure, we found that the classification process is to some extent negotiable. Customer requests are the main reason why the case company does not always conform to the classification rules. We expect the same practice to occur in other companies as well which, so far, is not clearly documented in the classification literature. Some studies do indicate that market characteristics are important (e.g. Olhager, 2003), but papers rarely address how customer wishes affect the classification. An exception is Huiskonen *et al.* (2003) who indicate that when a customer prefers price to delivery time as a service criterion, it may be possible to negotiate a change from a MTS to a MTO policy. Nevertheless, the negotiability of the classification does not make the systematically determined classification superfluous as the systematic classification provides the basis for negotiation. A direction for further research is to study the relation between formal classification rules and classifications in use and to which extent differences between these two are caused by negotiations with customers.

The example of a Slave SKU that could no longer benefit of wide ordering possibilities initiated by a Master SKU (Section 3.4.2) has two implications. Firstly, properly informing customers on consequences of operational bottlenecks such as minimal batch sizes in production is needed. As

operational bottlenecks become clearer for customers, realistic expectations can be fostered. Secondly, it illustrates the advantages of selecting a common recipe. In the case company a Slave SKU can have the same ordering flexibility as a Master SKU. Therefore new customers who value wide ordering possibilities should be tempted to select a common recipe by stressing the higher level of certainty that the product could be made in time if a common recipe is selected. We expect that selecting a common recipe in other production sites that are also hindered by minimal batches could result in increased ordering certainty as well.

The paragraph above stresses the interdependency of SKUs. However, the literature suggests that SKUs are commonly classified based on their individual characteristics. Conversely, we argue that interdependencies such as SKUs with the same customer (who requires that all SKUs have the same ordering policy) or SKUs that share recipes affect the classification. Further empirical research is needed to explore which dependencies exist and how to incorporate them into classification procedures.

Finally, the above shows that the framework of Van Kampen *et al.* (2012) is a suitable and useful tool to discuss SKU classifications, that helps structuring and decision making for classification in a company setting.

3.5.2 The classification over time

To put it simple, each change in a characteristic (e.g. changed demand volume) on which the classification is based could cause a SKU to be reclassified. In the case company this includes demand volume, minimal batch size, payment reliability, forecast accuracy and sequence in the cyclical production plan. Moreover customer wishes can also trigger the change of classification. But should we adapt a classification and how often?

Why should or shouldn't a classification be adapted?

As the characteristics on which the classification is based change it seems logical to adapt the classification. Half of the changes widen the ordering possibilities for a customer (from Slave to Master and from MTO to MTS) and adapting the classifications improves the competitive position of the company. The other half of the changes limit ordering possibilities for a customer (from Master to Slave and from MTS to MTO) and adapting the classifications reduces the risk of obsolete stocks for the company. However, both the customer and the company prefer that the classification is not changed too often. Every adaptation of a classification coincides with an amount of workload to adapt the new classification and to communicate or negotiate about the changed ordering possibilities. Therefore the decision to reclassify SKUs should be balanced between the competitive advantage and the reduced risk on obsolete stocks on one hand and the

effort to adapt and communicate the reclassification on the other hand. A direction for further research is to study how such trade-offs can be made.

How often should a classification be adapted?

Our results are somewhat inconclusive with respect to how often a classification should be revised. A short classification interval results in a high number of adaptations and therewith often in a lot of work, where the chance is high that changes will be changed back in a next period. A long classification interval results in a low number of adaptations but is unattractive in the situation of changing markets due to the great time lag when multiple time periods are included. Therefore in selecting the proper classification interval the trade-off has to be made between the advantages and disadvantages of different classification intervals. The above findings and the suggestions in Section 3.2.4 (product life cycle (e.g. Aitken, 2003) and seasonality (e.g. Olhager, 2003)) suggest that at least five characteristics affect the length of the classification interval (Figure 3.6). Further studies are needed to confirm these characteristics and to determine a structure for selecting the appropriate reclassification interval in various production settings.

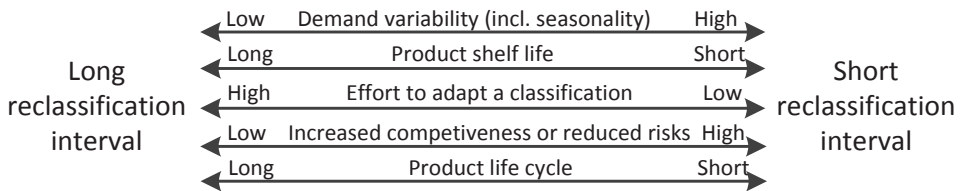


Figure 3.6: Influence of characteristics on the classification interval

3.6 Conclusions

The aim of our paper is twofold. Firstly, to understand how a company deals with conflicting characteristics of the food processing industry in their production strategy classification. Secondly, to explore the need for reclassification of SKUs.

The present paper shows that industry specific characteristics matter in SKU classification: the shelf life of a product requires that MTS products have a high level of forecast accuracy; cyclical production plans affect the minimal interval between two consecutive production runs and therewith the order lead-time; the minimal batch size affects the extent to which the order lead-time can be guaranteed (Master/Slave). Payment reliability has been detected as a relevant general dimension for production strategy

classifications in unstable markets, which, so far, was neglected in the classification literature.

Despite the limited attention the literature pays to reclassification, we argue that adapting a classification over time is required if the underlying characteristics vary over time. However, adapting a classification requires effort. Therefore, in the decision to reclassify SKUs one should balance the competitive advantage and the reduced risk on obsolete stocks on one hand and the effort required to adapt and communicate the reclassification on the other hand.

Classification and reclassification are less strict than we expected based on the literature. We found that customers can, to some extent, negotiate about the production strategy classification.

This study has managerial and theoretical implications. Our study shows the need for managers in the food processing industry to properly structure the classification and reclassification process. Only adapting classifications based on the request of customers or when being confronted with high stock levels, which used to be the approach in the case company, is not advisable, as opportunities are missed to either reduce risks or to increase competitiveness. At the same time the literature provides little guidance on the topic of reclassification. More studies are needed to explore and understand the trade-off between the effort to adapt a classification and the benefits that can be obtained by frequently updating the classification. When we understand the trade-off, further research could study what an appropriate interval is for updating a classification. Finally, the importance of reclassification implicates for literature that reclassification cannot be neglected and should be mentioned and further explored.

As with all studies, this study has some limitations. We carefully selected the case based on representative product and production characteristic for the food processing industry but we expect that the dominance of export products did affect the classification (Figure 3.4). Exporting to unreliable markets caused the inclusion of the dimension payment reliability. Nevertheless the other dimensions relate to common characteristics of the industry. Therewith the classification findings of our study are relevant for a wider range of food processing companies where we expect the need for reclassification to be relevant for all SKU classifications. Another limitation of our study is that we retrospectively classified SKUs over time due to the fact that no historical data was available regarding classifications. As a result we could only analyse the expected reclassifications and not the actual reclassifications. At the same time the interviews did provide the reasons for reclassification. A direction for further research would be to longitudinally study the compliance to the classification and the reasons for not complying.

4. Coping with product variety in the food processing industry: The effect of form postponement³

Abstract

Form postponement (FP) is an operations design approach that has been proposed in the literature as a solution for companies to handle increasing product variety and demand uncertainty. FP is possible in food, but the few authors that studied FP in food stress that food characteristics limit the benefits of applying FP. In the presence of these limitations it is unclear to which extent the same operational performance effects of applying FP can be expected in the food processing industry as reported in the general FP literature. In this paper we study how characteristics of the food processing industry affect the operational performance of implementing FP based on a case in a dairy company and a simulation model. We found that substantial operational performance improvements could be achieved when implementing FP diminishes the negative effects of some typical food processing industry characteristics. Large gains are possible in production settings with restricted batch sizes and cyclical plans that heavily influence the timing of production. However, a premise to maximise the FP benefits is that the other planning activities should match the new capabilities. Benefits are lower if the company cannot or does not adapt its organisational procedures.

4.1 Introduction

Form postponement (FP) is generally seen as a solution for companies to deal with the increasing variety and uncertainty in customer demand but it is unclear whether this solution is also beneficial in the food processing industry. The main idea of FP is to maintain products in a neutral and non-committed status as long as possible and to customize them at the latest possibility (Bowersox & Closs, 1996; Yang *et al.*, 2004). Therewith benefits can be obtained due to the maintained scale advantages while producing a customized product. A well-known example is the Hewlett-Packard case

³ An earlier version of this chapter is published as Van Kampen, T.J. and D.P. Van Donk (2010), Form postponement in the food processing industry: the case of a dairy company, proceedings of the 17th Annual EurOMA Conference, Porto, Portugal.

(Lee *et al.*, 1993). Instead of producing a customized printer, the company produced standardized printers and customized them in regional distribution sites with a manual and a power supply. However, in food it is difficult to split production in two steps due to the non-modularity of most products. As a result, the benefits of applying FP might differ in food. The central theme of the paper is therefore to understand the operational performance effects of applying FP in food processing industries.

Several authors have stressed the relevance of product and production characteristics in the selection of the appropriate postponement strategy (Zinn & Bowersox, 1988; Pagh & Cooper, 1998; Van Hoek, 1999, 2001; Brun & Zorzini, 2009). Regarding food processing it is known that industry specific factors hinder the application of FP (Van Hoek, 1999; Yang *et al.*, 2004). However, this does not imply that FP in food is not possible at all as several authors either provide examples or indicate that FP is a promising approach for the food processing industry (Morehouse & Bowersox, 1995; Van Hoek, 1997, 1999; Abukhader & Jonson, 2007). An important reason why FP is perceived as promising is the need to cope with the expected increasing variety in recipes, packaging formats and products, while demand is becoming less predictable. So far, the literature provides only few examples on actual FP implementations. Therefore it remains unclear to which extent FP is a beneficial approach to deal with the increasing product variety in the food processing industry. This is the major gap addressed in the paper.

The aim of the paper is to understand how food processing characteristics influence the performance effects of applying FP. In the study we combine an in-depth case study of an FP implementation in a dairy company with a simulation model in which a wider range of variables is studied representing other production settings. This paper adds to our understanding of FP and helps to understand the often-blurred performance effects. Specifically, it helps to understand how specific food processing characteristics influence or hinder the performance of FP. Finally it supports decision makers in the food processing industry who consider FP to remedy the increasing product variety and demand uncertainty.

The paper is structured as follows. The next section reviews related literature. Afterwards our methodology is presented. Subsequently the case company is introduced together with the results of the case study. Later on we present the design and the outcomes of simulation study. In the last part of the paper conclusions are drawn and suggestions are made for further research.

4.2 Literature review

This section discusses key findings in the postponement literature followed by more details of the literature on form postponement in the food processing industry.

4.2.1 Form postponement

The aim of postponement is to delay the product differentiation by maintaining the products in a neutral and non-committed status as long as possible (Bowersox & Closs, 1996; Yang *et al.*, 2004). As a result, postponement provides a way to deal with the increase in demand variety (e.g. Morehouse & Bowersox, 1995; Mikkola & Skjott-Larsen, 2004) while scale advantages are maintained. Not only maintained scale advantages are expected through implementing postponement but also gains such as inventory reductions and better-informed decisions thanks to reduced uncertainty as a consequence of delaying activities (Boone *et al.*, 2007; Hult *et al.*, Ketchen, 2010). A number of types of postponement (van Hoek, 2001) have been proposed such as time postponement (delaying forward shipment of goods), place postponement (maintaining goods at central locations in the channel) and manufacturing/form postponement (delaying the form and function utility of a product). Form postponement (FP) is the most common type of postponement and Zinn and Bowersox (1988) identified four subtypes of FP: labelling, packaging, assembly and manufacturing. In this paper we focus on FP affecting the manufacturing process.

Forza *et al.* (2008) contribute to the FP literature by evaluating the outcomes of previous FP contributions on six operational performance dimensions. They found that the operational outcomes of applying FP as reported in the literature are conflicting or hard to relate to each other. One of the reasons for contradicting findings or effects is that the application of FP might result in different outcomes depending on the location (or the change in the location) of the order penetration point (OPP) of a product. The OPP relates to the stage in the manufacturing value chain, where a particular product is linked to a customer order (also labelled as Customer Order Decoupling Point, Hoekstra & Romme, 1992). However, the OPP under study or the changes in the OPP are often not explicitly reported. Forza *et al.* (2008) therefore distinguish three types of FP: Type-I FP (from forecast driven to order driven), Type-II FP (remaining forecast driven) and Type-III FP (remaining order driven). Operational consequences are larger if the implementation of FP also changes the OPP and therewith the related production strategy (e.g. from forecast driven to order driven).

Several authors have stressed the relevance of product and production characteristics in the selection of the postponement strategy (see Zinn &

Bowersox, 1988; Pagh & Cooper, 1998; Van Hoek, 1999, 2001; Brun & Zorzini, 2009, for a full list of all relevant characteristics). Characteristics that are often identified are demand volume (FP is more relevant for smaller volumes), demand uncertainty (FP is more relevant if the risk for obsolete inventories is higher), number of variants (FP is more relevant in the situation that the number of variants is higher), and delivery time (FP is more relevant if delivery lead-time is more important).

Next to the characteristics, also FP enablers are identified (e.g. Forza *et al.* 2008). Process resequencing, component/process standardisation, product/process modularisation and delivery lead-time re-negotiation do not directly lead to FP but do facilitate that FP can be implemented. Companies that aim to implement FP could consider pursuing one of these enablers in order to increase the effect FP has on operational performance. So far, most applications of FP relate to discrete manufacturing (e.g. electronics, cars, furniture) with a notable lack of applications in process manufacturing (e.g. steel, oil, food). It is well known that production control in discrete and process industries differ (e.g. Dennis & Meredith, 2000; Fransoo & Rutten, 1994; Taylor *et al.*, 1981). Sousa and Voss (2008) stress that contextual conditions influence the effectiveness of management practices. Therefore, it is relevant to understand whether findings regarding FP in discrete manufacturing (e.g. the effect of demand volume and uncertainty) also apply in food processing production situations. More general, further guidance is needed whether typical food processing characteristics (contingencies) affect the operational performance of implementing FP.

4.2.2 Form postponement in the food processing industry

Regarding the use of FP in the food processing industry Morehouse and Bowersox (1995) predicted that the application of postponement would be increased by 2010 to the extent that half of all inventory throughout the food supply chains would be retained in a semi-finished state. Conversely, other papers identified that some food processing characteristics hinder the application of FP in the industry (Van Hoek, 1999; Yang *et al.*, 2004). More precisely they found that 1) the non-modularity of the product, 2) the production technology and its capital intensity, 3) the low value and perishability of products 4) the required short and flexible lead-times hinder implementing postponed manufacturing. Despite these limitations, quite a number of potential applications of postponement in the food processing industry have been indicated by Abukhader & Jonson (2007), who list over 50 possible FP applications and examples (e.g. postponing packaging, manufacturing, logistics of frozen, fresh and long life products). However, their list does not reveal the actual use or operational

performance of the FP implementation. As a result it is unclear whether these FP applications are really beneficial or that implementing FP leads to lower performance levels. To date, only two papers quantitatively illustrated FP in the food processing industry. Van Hoek (1997) provided an example of costs and benefits in a wine bottling case but compared estimates rather than real operational trade-offs between a postponed layout and two hypothetical structures. Akkerman *et al.* (2010) studied a flour company. However, the focus of that paper is on determining the number and composition of intermediate products in the mixing of flour.

Given the limited amount of papers on FP in food it is not surprising that several authors indicate that the effect of implementing FP in the food processing industry is still hardly investigated (Van Hoek, 1999; Abukhader & Jonson, 2007). Moreover, next to the four food characteristics that are mentioned above, several authors have indicated more characteristics that are typical for food processing industries (e.g. Akkerman and Van Donk, 2009). The effects of some of these characteristics are known, as they are typical for food but not specific for the industry (e.g. variable demand). However, for most characteristics it remains unclear if and to which extent they either accentuate or attenuate the operational performance of implementing FP. Therefore, in Table 4.1 we resume the main characteristics of food processing, from a planning perspective, indicated by Akkerman and Van Donk (2009) and assume how they affect the operational performance of implementing FP. The aim of the paper is to understand how the performance effects of applying FP is affected by these food processing characteristics.

Table 4.1 - Food processing industry characteristics and their assumed effect on operational performance

Food processing industry characteristic	Assumed effect on operational performance of implementing FP
-Perishable goods	-Reduced level of product losses or obsolete stock
-Shared resources	-Better resource utilisation (scale advantages) and therewith lower processing costs for postponed production
-Sequence dependent setup times	-Lower processing costs if set-up duration or set-up frequency is reduced
-Connectivity (limited intermediate storage)	-Improved flexibility if product differentiation is postponed unto intermediate storage
-Variable demand for end products	-Improved customisation and flexibility to react to changing demand
-Divergent product structure	-Larger scale advantages if product differentiation is delayed. Might limit FP if delaying product differentiation is not possible

4.3 Approach and empirical setting

4.3.1 Methodology

Our approach combines a case study with a simulation study. The case provides us insight in the basic mechanisms, whereas the simulation study allows us to explore the effects of the mechanisms observed in the case on a wider range of values. We chose for case study research as we noticed that little is known on how the outcomes of FP in the food processing industry are influenced by specific food processing characteristics. Case study research is seen as particularly appropriate for studying such “How” research question (Yin, 2003). Voss *et al.* (2002) stress that the case study approach has been one of the most powerful research methods in the development of new theory in operations management. Using the case study approach also allows us to study a phenomenon in its real life context (Yin, 2003). More specifically, we choose to conduct an embedded case study in which we acquire an in-depth insight by comparing two production layouts of a “typical case” (Yin, 2003 p. 41-43).

To broaden the applicability of the results found in the case study we use the findings from the case as a basis for the evaluation of a wider range of production settings. Simulation is chosen as it is often regarded as the proper means for evaluating different supply chain configurations (in this case FP options) due to the modelling flexibility (Van der Zee & Van der Vorst, 2005). More details on the design of the simulation are provided after the case study findings have been discussed.

For the case we selected a company that was representative for the food processing industry (the “typical case”, cf. Yin, 2003). Table 4.1 in the literature section describes the distinctive characteristics of the food processing industry. Not all these characteristics are present in all food processing companies, but we selected a dairy processing company where all these characteristics are present. The case company used FP to design a postponed production layout in parallel with the traditional layout. This provided us with a unique opportunity to simultaneously investigate a traditional and a postponed situation while other potentially influencing factors, such as market and product characteristics, were kept the same.

The aim of the case study was to collect data on how food processing characteristics influence the operational performance of applying FP in the company. An interview protocol was used indicating the subjects that would be covered and the questions to be asked to the informants. The interviews were held with employees from different functional departments (e.g. logistics, finance, and engineering) and combined with other sources (project documents, production data and demand data) to triangulate our findings. The interviews typically lasted one hour and were

recorded. The transcripts were sent back to the interviewees to verify interpretation. The six operational performance dimensions of Forza *et al.* (2008) were used to structure the analysis and to compare the traditional and the postponed production layout. Table 4.2 shows the dimensions and how the data on the dimensions (and the underlying product and production characteristics) were collected. Before we present the results of the case study we introduce the case company.

Table 4.2 - Data collection on the operational performance dimensions

Operational performance dimension	Data sources	Measurement
- Inventory holding costs	- Interview demand planner, project manager. - Quantitative analysis based on production planning and demand data of one year.	- The average inventory levels* of the product multiplied with the costs for the capital employment and storage space.
- Delivery lead-times	- Interview logistics manager, demand planner. - Quantitative analysis based on production and demand data of one year.	- The time between the ordering of a product and the time that the product is delivered*.
- Processing costs	- Interview project manager, engineer, manager controlling. - Data analysis on processing costs.	- The sum of energy costs, cleaning costs, labour costs, and depreciation/capital costs needed to produce the products.
- Transportation costs	- Interview logistics manager, project manager.	- The total costs to send a product from the company to the customer.
- Quality conformance	- Interview technologist, project manager. - Data from product analyses.	- The percentage of products that is produced to the customer's specification.
- Order specification ability	- Interview demand planner, logistics manager.	- The extent to which the order can be changed after it is placed at the company.

*As the production layouts were simultaneously present we compared the situation as if the production was either fully traditional or fully postponed.

4.3.2 Case description

The case company is a dairy processing plant that supplies products to more than 20 countries on four continents. To meet the customer demands a number of base components (mainly full cream milk and skimmed milk) are mixed and processed into more than 100 recipes. Out of these recipes over 700 products are produced on 18 packaging lines in different packaging formats (cans, bottles, cartons, and cups).

The order lead-times for most products are relatively long (up to three months between the ordering and the arrival of the products). Depending on the total volume and the variability of the demand, the products are either made to stock (MTS) (in the situation of high volume and low variability), which reduces the order lead-time, or made to order (MTO) (in the situation of low volume or high variability). Table 4.3 shows the presence of the typical food processing characteristics in the company.

Table 4.3: The presence of typical food processing characteristics in the case company

Typical food processing industry characteristic	Presence in the case company
-Perishable goods	-Recipes need to be packed in 24, 48 or 72h and the product needs to be shipped within 40 days to a few months due to restricted shelf life.
-Shared resources	-The four processors feed 18 packaging lines in multiple departments
-Sequence dependent setup/cleaning times	-The sequence affects set-up times in processing and packaging ranging from 0 to 240 minutes
-Connectivity (limited intermediate storage)	-Buffer tanks limit the amount of intermediate storage
-Variable demand for end products	-The demand volumes fluctuate particularly for African markets
-Divergent product structure	-Four processors produce 100 recipes which are packed on 18 packaging lines into 700 end products

An important dilemma in planning the production location is to balance the required high utilization of the processor (few set-ups when producing large batches) with the large variety of recipes that are produced to be packed in the packaging departments (many set-ups when producing each product individually). Currently, balancing these opposite forces is done by a cyclical production plan (restricting the weeks in which a recipe can be produced) and by decoupling the packaging phase from the processing phase by temporarily storing the intermediate product in tanks. Of course, the decoupling of these processes is limited due to the perishability of the product and the number of tanks. Any alternative production layout that reduces the number of recipes on the processor while all the end products could still be produced seems very attractive.

In the case company, a pilot-line has been constructed parallel to the traditional production layout. In the design of the line the postponement principle of delaying the customization has been applied (further referred to as “the postponed production layout”). The main change in the design of the postponed production layout as opposed to the traditional production layout was that instead of processing final recipes, the processing phase now produces two base recipes only. As a consequence, an additional

blending step was inserted just before the packaging phase to blend the base recipes along with some additives into final recipes. As a result, the product differentiation point in the processing stage was postponed from the processor to the blenders (see Figure 4.1). Given that the production strategy did not change the outcomes of the study relate to type II-FP (for the MTS products) and type III-FP (for the MTO products). Our results relate to both types of FP unless we specifically indicate only one type of FP.

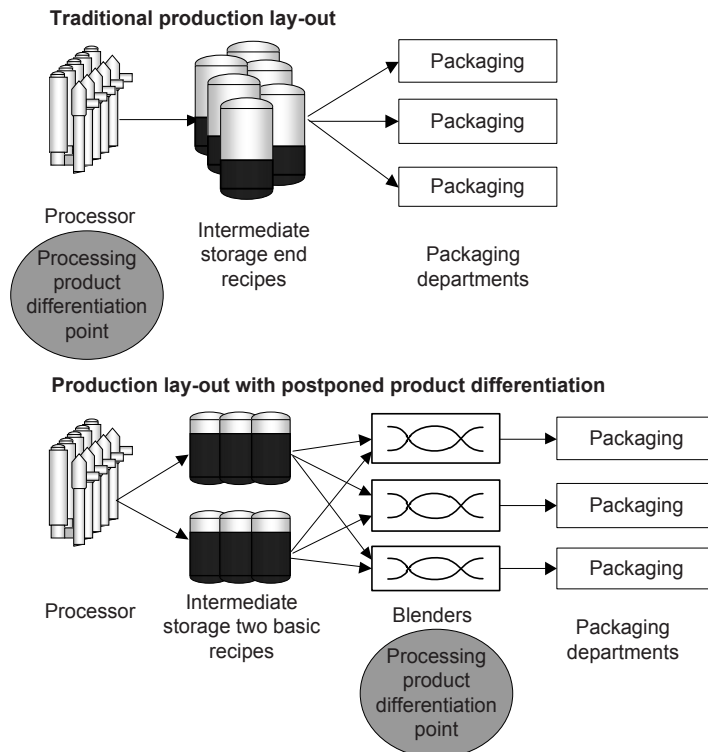


Figure 4.1: Traditional and postponed production layout.

4.4 Results

In this section we subsequently discuss the results from the case study and the simulation study.

4.4.1 Case results

The main advantages in the postponed production layout relate to the shift in differentiation point that now is placed at the end of the processing phase. By implementing the postponed production layout a number of

typical challenges in the food processing industry can be more easily dealt with:

- Available production capacity on the shared capital-intensive processor is higher as set-ups (e.g. cleanings) are minimized by only producing two base recipes.
- The minimal batch size for a recipe is reduced as it now depends on the blending stage instead of on the processor stage.
- The cyclical production plan (limitation which recipes can be made in a period) is relaxed as product diversity shifts from the processor to the blender (which has lower set-up/cleaning costs). Therefore more recipes can be produced in one period, which leads to an increase in the production frequency of a number of products.

The main advantages of the postponed production layout are summed up by the R&D manager as follows: *“The most important benefits of the new concept are the lower production costs which result from the more flexible process. The new process is more flexible than the current process, since product variety is introduced at a later phase in the process; economies of scale are coupled with flexibility.”* Below we discuss the effect on the six operational performance dimensions for the largest packaging department (representing 70% of the sales volume), as this department benefits from the pilot production line.

Inventory holding costs

The inventory holding cost for the type II-FP products are lower in the postponed layout (-14 %). However, there are considerable differences between the products (range 0 % to -75 %). Two reasons for the differences between the lowest and the highest reduction of the inventory holding costs came forward from our sources. The first relates to the effect that the minimal processing batch size (which is reduced) has on a product. For the fast moving products the traditional minimal batch size is not affecting the production frequency, but for slow moving products the minimal batch size gives rise to a low production frequency and relatively high inventories. As a result, large inventory reductions can be realized for slow moving products when shifting towards the postponed layout. A second rationale for the large spread in the reduction of inventory holding costs is the extent to which the cyclical plan limits the production frequency of a product. In the traditional setting, some products can only be produced every four weeks due to a limitation on the number of recipes within one week. In the postponed situation, the cyclical plan is relaxed and products can now be produced every week. Given that the cyclical plan and the minimal batch size both affect MTO and MTS products, we expect similar reductions in inventory levels for type III-FP to occur at the warehouse of the customers.

Form postponement in food

No differences were mentioned between the production layouts regarding the level of obsolete stocks.

Delivery lead-times

In the postponed production layout the recipe is differentiated up to 24 hours later compared to the traditional layout. This results in more flexibility as the base recipes can be used for the production of other end recipes as well. However, the planning of the packaging departments, the ordering of the packaging materials and the arranging of the sea shipments is done a number of days up to three weeks ahead of the production. Therefore, changing to a postponed production layout does not result in a general reduction of the delivery lead-times or in a change of production strategy (MTS or MTO). However, for the products that were restricted by the cyclical plan (MTO; type III-FP), a reduction in the delivery lead-time can be noticed (up to three weeks for products with special recipes). The reason for the reduction is that products using an uncommon recipe do not have to wait any more for the next possibility in the cyclical plan to be produced due to the reduced set-up times.

Processing costs

In the postponed production layout the total set-up time of the processor is minimized as the two base recipes can be produced consecutively without a set-up instead of the sequence dependent set-ups between recipes in the current layout (which last up to 4 hours). Therewith the processing efficiency improves which results in savings related to energy use, material use (due to less product losses) and cleaning cost on the processor. However, additional - but much smaller - energy, product and cleaning material losses occur in the blending step which is added to the production process. The postponed production layout implies higher investments, which result in 2.7% higher conversion costs (costs excl. materials). Yet, savings related to labour and production support, counterweigh the increased depreciation costs. Altogether both scenarios do not differ significantly.

Transportation costs

Transportation costs mainly consist of the cost of transporting a container from the production site to a regional warehouse. Transportation has a considerable impact on the price of the product due to the relative low value of the product. Therefore the shipment of the products to a customer is commonly done in full container loads. Postponing the production differentiation does not affect the full container policy and therefore no noteworthy changes occur in the transportation costs.

Quality conformance

In the postponed production layout the final recipes are blended from two base recipes and a number of other components just before the products are packed. Consequently, end recipes need to be produced “*first time right*” where the traditional option to slightly change the recipe in the tank is eliminated. However, the increase in the chance of a failure is compensated by an increase in the quality control of the components. As a result the recipes have the same quality conformance in both production layouts, which is confirmed by quality tests.

Order specification ability

As the production specification is only done a number of hours (up to 24h) later in the postponed production layout, only a small time saving can be achieved in which the production plan can be modified. However, in the case company the time gain vanishes when the related frozen horizons (fixed time fence in which plans are not adapted. This affects planning the packaging departments, the ordering of packaging materials, and arranging shipments) are taken into account. Therefore no gains are noticed in the case company related to the order specification ability in the postponed production layout. Table 4.4 summarizes the outcomes on the six operational performance dimensions.

Table 4.4 - Performance effect of the shift towards the postponed production layout

Operational performance dimension	Change	Main drivers
- Inventory holding costs	- Reduction of 14% (range 0 to 75%) type II-FP but probably also for type-III-FP	- Reduced minimal batch size - Higher production frequency due to relaxed cyclical plan - No change in obsolete stock
- Delivery lead-times	- Reduction of up to 3 weeks for type III-FP	- No general reduction due to related frozen horizons - Reduced delivery lead-time for MTO products due to relaxed cyclical plan
- Processing costs	- No significant change	- Improved processor effectiveness due to reduced set-ups - Additional set-ups on blender - Less labour costs - Additional depreciation
- Transportation costs	- No significant change	- Shipment still on full container
- Quality conformance	- No significant change	- Higher risk due to in-line production - Improved control
- Order specification ability	- No change	- Potential small improvement but related frozen horizons limit benefits

4.4.2 Case discussion and simulation design

The postponed production layout results in an improved performance as inventory levels are lower (for MTS products), order lead-time is shorter (for MTO products) while the other operational performance dimensions are the same. Not all the characteristics of the food processing industry (Table 4.1) did affect the performance outcomes but some relate to the main drivers. The four main drivers that cause the performance changes (Table 4.4) are the change in minimal batch size, the relaxed cyclical production plan (due to reduced set-up costs), the possibility to change related frozen horizons (e.g. ordering packaging materials) and the changed components of the processing costs. We explain the drivers below.

- The implementation of FP resulted in a shift of the batch restriction from the processor to the blender leading to a reduction in the minimal production batch. Particularly the inventory levels for low demand products were reduced.
- The initial/original cyclical production plan in the case company limits the number of recipes within one week. Due to the implementation of FP set-up costs were lowered and the cyclical plan could be relaxed resulting in lower inventory levels and a reduced lead-time for some MTO products.
- Surprisingly, implementing FP did not result in an overall improvement in delivery lead-time or order specification ability. The absence of changes in the frozen horizon of the packaging department and the release of orders for the packaging materials resulted in an unchanged performance for both alternatives on these dimensions.
- A mixed outcome was found for the overall processing costs. Some components were positively but others negatively affected, leaving the processing costs about the same. However, we are convinced that the processing costs are influenced by the specific available technology and design choices made by the company. Therewith the generalizability of this part of the results is limited.

In order to better interpret the case outcomes, a simulation study was designed. In the experiments a spectrum of values around the drivers of the case outcomes are evaluated to provide general insight in the mechanisms. As the processing costs are likely to be case-specific, no further experiments were executed with this factor. Opposing the hybrid MTO-MTS situation in the case, we chose to model the MTS situation only (type II-FP) as demand uncertainty is zero for MTO products (Type III-FP) due to the fact that production is only planned after orders have arrived (Forza *et al.*, 2008). The technical details on the simulation can be found in Appendix 1. Below we discuss how the three drivers are included in the experiments.

The minimal batch size reduction highly affected the inventory levels. However, the outcomes of the case do not reveal the nature of the relationship. For example, it is not clear what the effect on the inventory levels would be if the change in the minimal batch size due to the application of FP would be different, or how the outcomes would be if the number of recipes would increase or decrease. Therefore, in Series I of our simulation study we explore how recipe variety and the minimal batch size affect the delivery performance and inventory levels (Table 4.5).

Table 4.5 - The factors considered in the series of experiments

	Number of recipes	Min batch size (tons) *	Cyclical plan (weeks)*	Frozen horizon (weeks)	Demand uncertainty (CoV)
Series I	10, 15, 20, 25	30, 60, 90	8	1	0.3
Series II	15	60	2, 4, 8, 16	1	0.3
Series III	15	60	8	1, 2	0.2; 0.3, 0.4

* In the postponed layout recipes can be made weekly with a minimum batch size of 10 tons.

The cyclical plan specifies which recipe is made which week and could be relaxed due to the FP implementation. The use of cyclical plans (or campaign production) is quite common in processing industries (e.g. Gunther *et al.*, 2006; Shah, 2005; Kallrath, 2002). However, it is unclear how the interval of the cyclical plan affects the operational performance of implementing FP. Therefore in experiment Series II we evaluate the operational outcomes of different cyclical plans (ranging from 2 to 16 weeks) and compare these outcomes to the postponed situation where each recipe can be produced weekly. We used the cyclical production plan of the case company as a basis for constructing the different cyclical plans. In Appendix 2 these cyclical plans are shown.

Inability to change frozen horizons for the weekly release of the production schedules and the release of orders for the packaging materials limited the benefits of FP in the case company. Previous studies also suggest the need to adapt the organizational processes to the new production layout in order to obtain the full benefits of the shift towards postponement (Skipworth & Harrison, 2004; Trentin & Forza, 2010; Trentin *et al.*, 2011). Adapting the organization to the changed postponement strategy might be a particularly relevant consideration in the food processing industry as it is often seen as a big limitation in increasing planning flexibility (Van Wezel *et al.*, 2006). In Series III of the simulation study we therefore evaluate the operational consequences of FP in the situation of a frozen horizon of one

and two weeks (the period in which the production plan cannot be changed due to organizational arrangements). Besides the increased flexibility towards the customer, another gain of a reduced frozen period is the reduced risk of producing the wrong product. This risk is higher when demand is more uncertain. Therefore we evaluate the change in the frozen period under different levels of demand uncertainty (different coefficients of variation i.e. standard deviations as a fraction of the mean weekly demand). Table 4.5 shows the distribution and the levels of uncertainty in the experiments.

In the simulation study we expect, in line with the performance outcomes in the case company, the main differences to occur in the level of inventory. Inventory levels (the sum of the average inventory level of all SKUs during the simulation period) are therefore used to evaluate the performance in the simulation model. A positive side effect of higher inventory levels could be that a higher delivery performance is achieved. Therefore delivery performance (the fraction of units which are delivered in time) is included as a second evaluation dimension.

4.4.3 Simulation results

The results for each series of experiments are presented in two figures: one showing delivery performance, and one depicting inventory levels. The results are based on 10 simulation runs using different seed values where the run length was set to 1000 weeks. For more technical details see Appendix 1.

Differences between the traditional and the postponed layouts have been tested for statistical validity using a paired-t approach with a 99% confidence interval (Law & Kelton, 2000). The tests pointed out that differences greater than 0.03% for delivery performance and 1.04% for inventory levels should be considered significant.

Number of recipes and the minimal batch size (Series I)

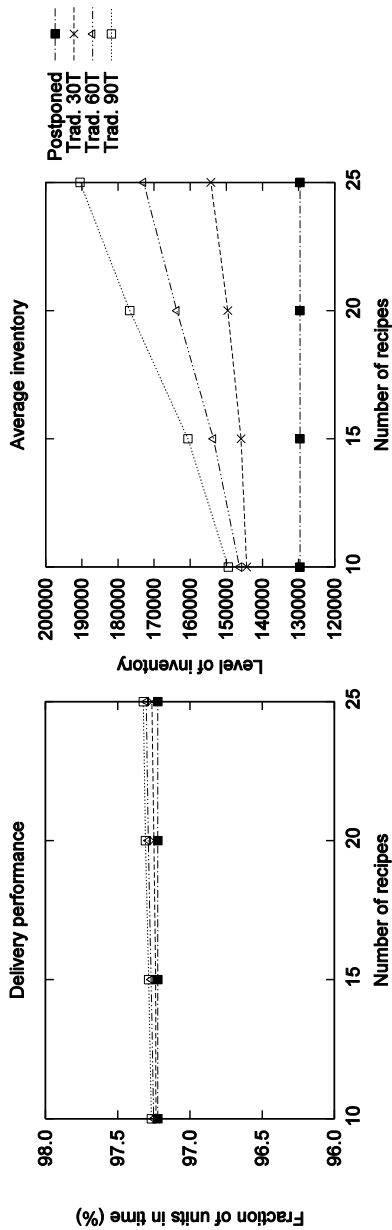
The delivery performance (Figure 4.2) in the traditional layout is slightly better than in the postponed layout when the number of recipes increases (at 20 recipes the difference is small but significant). The difference increases for larger minimal batches. In the postponed layout, the inventory levels (Figure 4.3) are the same for different levels of recipe variety due to the fact that regular production is not hindered by the minimal batch sizes. In contrast, the inventory levels in the traditional layout are significantly higher due to the larger minimal batch size and increase rapidly with the number of recipes.

Cyclical plans (Series II)

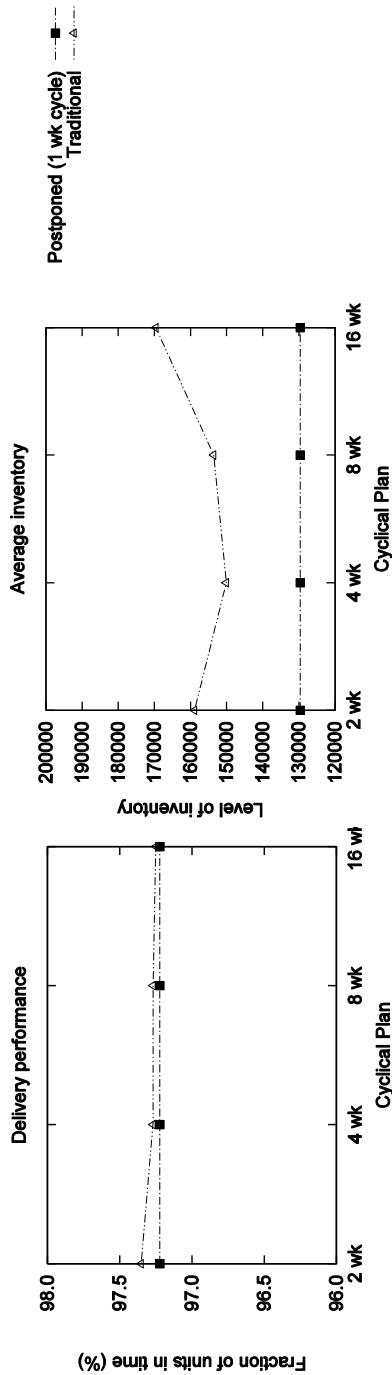
In the third set of experiments, the weekly production cycle in the postponed layout is compared to production cycles of a different length in the traditional layout. Figure 4.4 shows a small but significant difference on delivery performance for the two-week interval, which diminishes as the cyclical plan concerns a longer period. For all schedule lengths the postponed layout significantly outperforms the traditional layout with respect to the inventory levels (up to 31% for sixteen weeks). For intermediate long cycles, inventory levels in the traditional layout drop (specifically at four weeks), but increase for a cycle of sixteen weeks. In a four weeks scheme demand for different stock keeping units (SKUs) is clustered over a longer period than in the two weeks scheme resulting in lower inventory levels due to the required minimal batch sizes. In the sixteen weeks schedule, higher inventories are the result of the larger batch sizes needed to cover the demand during the whole cycle length. The eight weeks schedule is close to the four weeks schedule with only slightly higher inventories.

Frozen horizons and demand uncertainty (Series III)

In Series III we investigate the effect of frozen horizons - either one or two weeks before the actual production takes place - for different levels of demand uncertainty. Figure 4.6 shows a delivery performance decrease when demand uncertainty increases for all settings. Comparing the traditional layout with the postponed layout shows small differences in delivery performance (up to 0.1%) but large differences in inventory levels (up to 16%). Releasing the production plan, one instead of two weeks ahead of production, results in a higher delivery performance (range 0.7-2.2%) and lower inventory levels (range 1.0-2.6%) in both layouts. The best delivery performance at the lowest inventory levels can be achieved in the situation of a postponed layout and release of the production plan one week ahead of production.

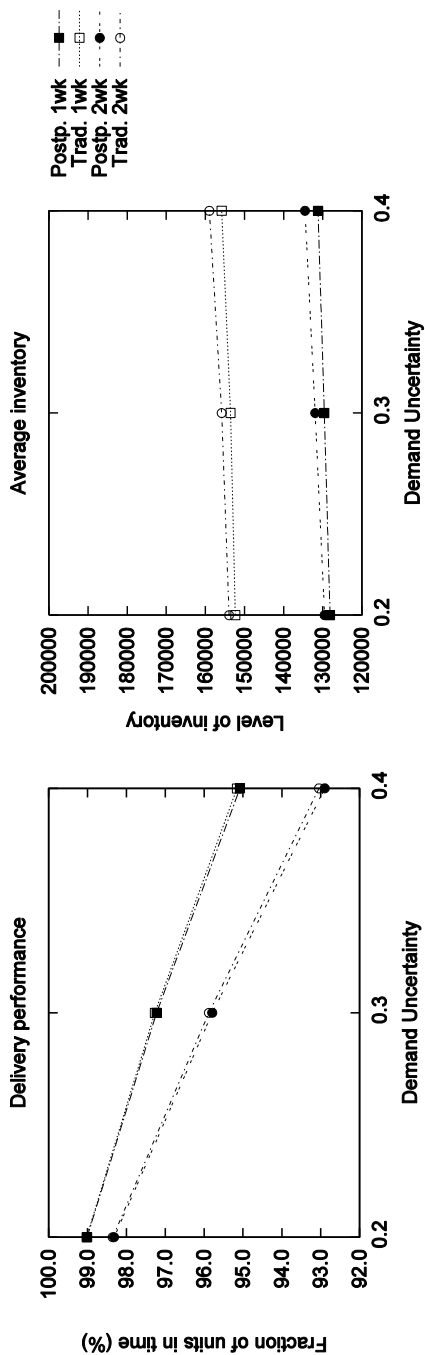


Figures 4.2 and 4.3: Delivery performance and inventory levels for various levels of recipe variety



Figures 4.4 and 4.5: Delivery performance and inventory levels for various cyclical plans.

Note that weekly cycles are used in the postponed production setting.



Figures 4.6 and 4.7: Delivery performance and inventory levels for various levels of demand uncertainty

4.5 Discussion

This study shows that a number of findings on FP from discrete production settings apply to food processing industries. However, it also reveals that a number of typical food characteristics (but not all) matter when implementing FP. Below, we discuss our main findings related to operational performance.

Contingencies have a strong effect on the operational outcomes of applying FP. FP is more beneficial in production situations with a high variety for end products or recipes (case outcomes and simulation Series I), in line with Pagh & Cooper (1998) and Van Hoek (2001) or when demand is more uncertain (simulation Series III). Moreover, when food processing characteristics such as minimal batch sizes and cyclical production plans (expensive set-ups) greatly restrict production planning, large gains can be expected if implementing FP as FP potentially relaxes such constraints (case outcome and simulation Series I and II).

Frozen horizons should match the capabilities gained by implementing FP in order to reduce inventories (case outcomes and simulation Series III). Despite the delayed customization in the case company, the delivery lead-time could not be shortened because the company was not able to adapt the frozen horizons for other related plans such as packaging materials. Therefore, a prerequisite for lead-time and order specification improvements is that the organization is able to adapt planning procedures. Such organizational and planning related changes are also suggested by Skipworth & Harrison (2004) and Trentin *et al.* (2011).

The literature suggests that processing costs increase and quality control decreases when FP is implemented (e.g. Lee and Billington, 1994; Pagh and Cooper, 1998). Contrary we found no significant change on both processing costs and quality control. An explanation for the difference is the different scope of the FP implementations. These authors suggested the need for duplication of assets, and lower knowledge on quality control, which are not a necessary or logical consequence if the entire production remains on a single location, as was the situation in the case company. Therefore it is important to consider the scope (single or multiple locations) of an FP implementation. We submit that for the process industries it will be more common to implement FP on a single location as duplication of assets is expensive (which causes the strong focus on capacity and resources utilisation in Table 4.1). Therefore we expect a similar scope in other cases in this industry.

The product differentiation activities in the case were postponed for one activity (processing) resulting in a delayed differentiation for most products of 24 hours. We expect that larger FP performance effects can be achieved if

either the scope is extended to include packaging as well or when the supply chain including packaging becomes capable to deal with last minute changes. Keeping more packaging stocks or standardising packaging formats enables the company to react faster and therewith to acquire more FP benefits.

Our case study shows that applying a new technology enables the company to reach FP benefits. The literature shows a large gap between the high expectations of FP in food processing industry on one side (Morehouse & Bowersox, 1995; Abukhader & Jonson, 2007) and the limited number of applications on the other side (Van Hoek, 1999; Abukhader & Jonson, 2007). In the case company, FP was realized by introducing an innovative technology. Therefore, we expect that other food processing industries should consider alternative production technologies in the context of implementing FP to maximise the FP benefits.

Finally we want to make a remark regarding our approach. Boyer and Swink (2008) argue that a holistic understanding of operations and supply chain management phenomena is needed. They propose the use of multiple approaches but focus on combining empirical methods. This study shows that other combinations can be useful as well. The combination of a case study with a simulation study results in an in-depth insight in the case company along with general insights on particular dimensions.

4.6 Conclusions and future research

The aim of the paper is to understand how industry specific characteristics influence the operational performance of applying FP in the food processing industry. In line with previous findings on FP in discrete processing settings we found that applying FP in food processing industries is suitable for production settings with a high product variety and high demand uncertainty. Additionally, we found that two specific process industry characteristics that usually limit flexibility and influence the operational outcomes might be mitigated by implementing FP. Firstly, implementing FP can relax restrictions on minimal batch sizes and as such enable large reductions in inventory levels. Secondly, FP can relax the strictness of cyclical production plans, which can result in shorter production intervals and in turn reduced stock levels, as well. For MTO (type III-FP in the terminology of Forza *et al.*, 2008) products a reduction in the delivery lead-times was noticed as well.

As with all studies, ours has some limitations. We carefully selected the case based on representative product and production characteristic for the food processing industry but not all operational performance dimensions were affected. However, the characteristics and performance dimensions

that were included in the simulation study are typical for food processing industries, and therefore these dimensions provide general insight for this type of industry. Future research should investigate other production settings to investigate if these affect the performance dimensions that were not affected in the study. The list of Abukhader and Jonson (2007) could be used to select such settings. A second limitation could be that the unit of analysis in our approach is a single location of a company. The literature provides examples why, for example, quality conformance changes when production is split over multiple locations. Yet, Van Hoek (2001) suggested that splitting the process over multiple locations is uncommon in food processing. Therefore, a direction for further research is to study a broad range of FP implementations in food processing companies to confirm whether it is common in food that the scope of an FP implementation is a single production location.

This study has several implications for theory and practice. Firstly, typical planning mechanisms of the food processing industry greatly affect the operational outcomes of applying FP. Our study shows that such characteristics should be considered in understanding how FP can be implemented and be made beneficial. This important result should be taken into account by managers when implementing FP and by academics in future research. Future research should compare the application of FP in multiple companies from various industries in order to confirm the typical planning mechanisms we found and to identify possible other planning mechanism as well. An example of such an approach is the work of Van Hoek (1999). Secondly, the case study shows that logistical advantages of both implementing FP and new technologies can provide new possibilities for planning and control for meeting market demand. Therefore production technology should be considered next to FP. Further research could study how production technology next to logistics can be used to meet the customer demand, but also how such technology can be made beneficial by changing organizational and planning procedures. Finally, the company should organise its processes such that the full potential of an FP implementation is achieved. Frozen horizons need to match the production capabilities in order to acquire the order lead-time or order specification ability benefits.

4.7 Appendices

4.7.1 Appendix 1 – specification of the simulation model

In the simulation model we compare the performance of a traditional and a postponed production layout (for one processing and one packaging department). The dairy company as described in Figure 4.1 is used as the base for the design of the model. The comparison focuses on differences caused by the chosen technology in these production layouts and zooms in on a situation with one blender and one packaging department. For the comparison we looked into planning decisions in these layouts and not into scheduling decisions. As a result, intermediate storage tanks were not modelled and we assumed that production volumes of products within one week could be combined to meet minimal batch requirements on a recipe level.

The decision making process for both production layouts is the same. Two decisions are made each period namely whether a product is produced and in what volume. However, to come to these decisions a number of steps need to be taken (see Figure 4.8). In the model orders for the same product are fulfilled on a FIFO basis were we assume that no orders are lost when deliveries are late. The main technical differences between the traditional and the postponed layout are the minimal batch size (which can be reduced in the postponed layout) and the cyclical plan (which can be relaxed in the postponed layout). These factors and other experimental factors (Table 4.5) influence the outcomes of the model. Figure 4.8 visualizes the model.

The performance of the series of experiments is measured on two scales, namely delivery performance and inventory level. Delivery performance is measured as the fraction of units that are delivered in time (total units in time delivered/total units delivered). Inventory level is measured as the sum of the average inventory level of all SKUs during the simulation period.

Form postponement in food

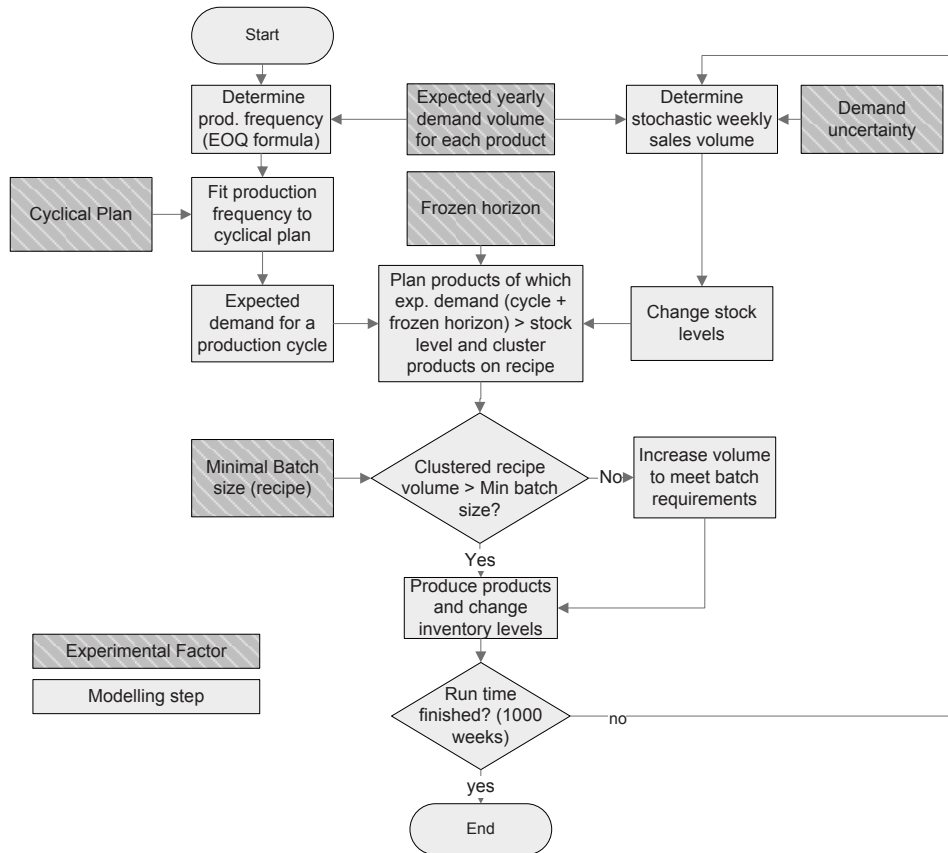


Figure 4.8: Decision structure in the model

Table 4.6 shows the fixed factors in the model. We have set the yearly demand such that the machine utilization is around 80% (exact percentage depends on the number of set-ups). For the experiments we fixed the number of products to 100 as we investigate product variety on a recipe level. These products are produced on stock (MTS) based on the forecast of the demand. Opposing the hybrid MTO-MTS situation in the case, we chose not to model the MTO products, as demand uncertainty is zero given that production is only planned after orders have arrived. The yearly demand for the different products can be described following a Pareto curve where 20 products account for more than two third of the demand volume. The demand for the products occurs weekly and follows a normal distribution (mean = yearly demand volume of a product/52; standard deviation = $(0.2-0.4) \cdot \text{mean}$, depending on the level of uncertainty). The normal distribution was protected against the possibility that it would generate a negative

demand. For reasons of simplicity we kept the same level of safety stock for all the products.

Table 4.6 - The values of the fixed factors

Fixed factors	Value
Total yearly demand	100.000 Tons
Number of products	100
Range yearly demand per product	125-6600 Tons
Duration of a period	1 week
Distribution for weekly demand	Normal
Safety stock level	0.3 weeks

The software package that we used to carry out the simulation experiments is Tecnomatix Plant Simulation 8.2 TM. The system can be described as a production system where the demand is generated weekly and where the processor has sufficient production capacity to meet the average demand. We start with inventory levels that can meet the average demand until the next production moment in the production cycle plus the safety stocks. No warm up period was used to arrive at the steady state, which was confirmed by the Welch procedure (Law & Kelton 2000). A total of 10 runs were carried out using different seed values where the run length was set to 1000 weeks for each experiment.

4.7.2 Appendix 2 – the cyclical production plan

Campaign planning or cyclical planning is typical in process industries (e.g. Shah, 2005). However, different approaches exist to determine the cyclical plan. For example, Gunter *et al.* (2006) fix the production sequence but not the timing, where Strijbosch *et al.* (2002) only fix the timing for the products. In the case company a cyclical plan was used of four weeks that limited the timing when a recipe could be produced. A few recipes could be produced weekly or bi-weekly where the majority of recipes could be produced only every four weeks. We used this approach as reference for the cyclical plans in our model. Table 4.7 shows the minimum production intervals for the recipes in the cyclical plans. The values represent the minimum number of weeks between two successive production batches of the same recipe. The decision whether the recipe is actually produced in a week depends on the question whether the inventory levels of the products that use the recipe can cover the expected customer demand until the next production possibility.

Table 4.7: Minimum number of weeks between two successive production batches for a recipe in the different cyclical plans

Recipe	Postponed	2 weeks Schedule	4 weeks Schedule	8 weeks Schedule	16 weeks Schedule
A	1	1	1	1	1
B	1	1	1	1	2
C	1	1	1	2	2
D	1	1	2	2	4
E	1	1	2	2	4
F	1	2	2	4	4
G	1	2	2	4	4
H	1	2	4	4	8
I	1	2	4	4	8
J	1	2	4	4	8
K	1	2	4	4	8
L	1	2	4	8	8
M	1	2	4	8	8
N	1	2	4	8	16
O	1	2	4	8	16
P	1	2	4	8	16
Q	1	2	4	8	16
R	1	2	4	8	16
S	1	2	4	8	16
T	1	2	4	8	16
U	1	2	4	8	16
V	1	2	4	8	16
W	1	2	4	8	16
X	1	2	4	8	16
Y	1	2	4	8	16

5. Safety stock or safety lead-time: coping with unreliability in demand and supply⁴

Abstract

Safety stock and safety lead-time are common measures used to cope with uncertainties in demand and supply. Typically, these uncertainties are studied in isolated instances, ignoring settings with uncertainties both in demand and in supply. The current literature largely neglects case study based contexts and, often, single product situations are investigated in which machine set-ups are not considered. Based on the problems and findings in a case study, we investigate the effects of safety stock and safety lead-time on delivery performance in a multi-product setting. The outcomes of the extensive simulation study indicate that utilising a safety lead-time results in a higher delivery performance where there is a variable supply, whereas having a safety stock results in a higher delivery performance where there is unreliable demand information. In contrast to earlier findings in the single product situation, our study shows that managers facing the combination of unreliability in demand information and supply variability in a multiple product situation should opt for a safety lead-time as the most effective way of improving their delivery performance.

5.1 Introduction

Typically, production stages in a process industry are tightly coupled, with only a small amount of intermediate inventory available relative to the production speed (Taylor *et al.*, 1981). In such a situation, these systems are vulnerable to machine breakdowns and last minute order changes. The process industry is capital-intensive, and hence production capacity is highly utilized. In the absence of excess production capacity, safety stock and safety lead-time are common measures used to deal with supply variability and unreliable demand information (e.g. Buzacott and Shanthikumar, 1994). The use of safety lead-time provides planners in such

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systems with mix flexibility. This is especially helpful in dealing with supply uncertainties, such as machine breakdowns. On the other hand, having a safety stock increases the system responsiveness, which is helpful in dealing with short-term changes in demand. The presence of both types of uncertainty, however, tends to complicate matters in terms of the trade-off between the benefits of safety stock and safety lead-time. Based on an industrial case study, we have conducted an extensive simulation study that addresses this trade-off and investigates the real life situation with both supply variability and demand uncertainty.

We found similar problems being studied in two fields. The literature on Material Requirements Planning (MRP) discusses planning and controlling production and inventory levels of various products and materials (e.g. Koh *et al.*, 2002, Dolgui and Prodhon, 2007). In this field, uncertainties in demand and supply are typically studied in isolation. Further, those papers that do investigate uncertainties in both demand and supply largely restrict uncertainty in demand information to volume changes. Not surprisingly, the need for further research on supply planning under simultaneous demand and lead-time uncertainties is acknowledged in a recent review by Dolgui and Prodhon (2007).

While the relevant literature we found on MRP tends to stress *intra-company* tuning of activities, other researchers have considered the way Advance Demand Information (ADI) may be beneficial for improving *inter-company* activity tuning. Here, research efforts are aimed at improving insights into the costs and benefits of acquiring more reliable demand information for company planning (e.g. Karaesmen *et al.*, 2004, Kunnumkal and Topaloglu, 2008). In this field, various types of demand variability are considered such as changes in volume, product type and due date. Again, only very few papers combine supply uncertainty and demand uncertainty. Further, the papers that do combine these uncertainties address only a single product situation.

Given the fact that both these fields largely ignore supply planning when there are uncertainties in demand and production, the question remains as to what buffer measure to use under which circumstances. The question whether to use safety stocks or safety lead-times to cope with uncertainties in demand and supply has been considered over the years (see e.g. Guide and Srivastava, 2000, pp. 227-228) but findings are inconclusive as to when safety stock or safety lead-time is the better option.

The aim of the study is to investigate the effectiveness of safety stocks and safety lead-time in the presence of both demand and supply uncertainties. More precisely, we investigate the ability of different levels of safety stock and safety lead-time to cope with (1) supply variability, (2) alternative types of unreliability in demand information and (3) the

combined effect of unreliability in demand information and supply variability. The effects of safety lead-time and safety stock are measured along two dimensions: delivery performance and average inventory level in the system. An extensive simulation study has been used to obtain insights in a range of situations that can aid planners to choose between these two alternatives.

Following the suggestion of Guide and Srivastava (2000) to model real environments, the experimental settings in the simulation study are based on an industrial case study concerning a can supplier in a dairy supply chain. Essentially, the activities of the can supplier are aligned to a packaging firm, where the processes are decoupled within a warehouse. Decoupling the processes by using safety stock or safety lead-times makes the system less vulnerable to machine breakdowns in the can factory (supply variability) and demand changes from the packaging firm (demand unreliability).

The paper is structured as follows. Section 5.2 reviews related literature. Next, Section 5.3 discusses the case study that motivated our research. The main focus will be on the system characteristics and the dilemmas faced by the planner in realising an effective supply. Together these underpin the design of the simulation study, described in Section 5.4. In Section 5.5, the results of the study will be presented, and subsequently discussed in Section 5.6. Finally, Section 5.7 summarises the main conclusions and makes suggestions for further research.

5.2 Literature review

In this paper, we are studying the use of safety stocks and safety lead-times as a way of aiding the operational planning of tightly coupled manufacturing stages with uncertainties in both supply and demand information. We define safety stock as the average amount of inventory kept in hand to allow for short-term uncertainty in demand and variability in supply (Silver *et al.*, 1998). In line with Hariharan and Zipkin (1995), we define safety lead-time as the difference between the release time and the due date minus the supply lead-time of the product, where supply lead-time is defined as the time that is required to produce the order (Hariharan and Zipkin, 1995). Variability in supply occurs because the output is not constant for a range of reasons including equipment failures. Demand variability is related to uncertainty in the volume, product type, or the timing of incoming orders, which may cause last minute changes to operational production plans.

Various authors have studied the use of safety stocks and safety lead-times, but their findings are inconclusive with respect to the question as to whether it is better to use safety stock or safety lead-time. Liberopoulos *et*

al. (2003) show that in cases with limited capacity, safety stock and safety lead-time are fully interchangeable. On the other hand, Buzacott and Shanthikumar (1994) show that safety lead-time is usually only preferable to safety stock when it is possible to make accurate forecasts of requirements over the production lead-time. Guide and Srivastava (2000) review the use of safety stock and safety lead-time and conclude that there are no methodologies that provide a general solution. They further suggest that future research should focus on models that reflect real environments.

The required amount of safety stock or the length of a safety lead-time is influenced by the level of uncertainty experienced in a production unit. If the uncertainty in demand information (e.g. Karaesmen *et al.*, 2004) or supply variability (e.g. Karaesmen, 2003) is reduced, the delivery performance will improve or, alternatively, the safety stock or safety lead-time can be decreased. Such reductions in uncertainty can lead to cost reductions (Kunnumkal and Topaloglu, 2008, Wei and Krajewski, 2000).

Three recent reviews on managing uncertainties in MRP environments show that, to date, studies have been largely restricted to a single source of uncertainty, related to either supply or demand. Dolgui and Prodhon found that 22 out of the 26 papers reviewed considered either demand or lead-time uncertainty (Dolgui and Prodhon, 2007, Tables 2-4 pp. 274-275). Mula *et al.* distinguished six different types of uncertainty in their review, and 64 out of 87 papers considered only one type of uncertainty (Mula *et al.*, 2006, Tables 5-8 pp. 275-281). Koh *et al.* distinguished four types of uncertainty in their review, and 21 out of 37 papers considered only one of these (Koh *et al.*, 2002, Figure 3&4 pp. 2403-2412). A limited number of papers in the MRP field do combine supply uncertainty and demand uncertainty. In these papers, demand uncertainty is often related to volume changes (e.g. Schmitt, 1984, Ho, 1993, Brennan and Gupta, 1996, Molinder, 1997, Ho and Ireland, 1998). Alternatively, Koh and Saad combine volume changes with changes in product specification (2003) or in due-dates (2006). Given the findings from the reviews, it is not surprising that Dolgui and Prodhon (2007) and Mula *et al.* (2006) conclude that planning under different types of uncertainties is a promising area for further research.

Having looked at the aforementioned studies within the MRP context, we concluded that they tend to display a somewhat *intra-company* focus, and often consider demand information as an exogenous factor. However, some researchers have discussed the way in which Advance Demand Information (ADI) could be beneficial for *inter-company* tuning of activities. Here research efforts are aimed at improving insights into the costs and benefits of acquiring more reliable demand information for company planning (e.g. Karaesmen *et al.*, 2004). Product ADI concerns the amount, the product type or the timing, and reduces demand uncertainty. ADI becomes more

beneficial when its unreliability is reduced (Tan *et al.*, 2007). Greater accuracy in demand information can reduce the need for inventory (e.g. Bourland *et al.*, 1996, Ozer and Wei, 2004), improve reliability (Bourland *et al.*, 1996) and reduce the need for excess supply capacity (Ozer and Wei, 2004).

The literature on ADI often assumes perfect demand information and few papers address uncertainties in demand. The papers that do study demand uncertainty relate uncertainty to due-date setting (Tan *et al.*, 2007), order cancellations (Thonemann, 2002, Liberopoulos *et al.*, 2003, Tan *et al.*, 2007), incomplete order data on product type (Thonemann, 2002) or partial schedules, where part of the orders are still unknown (Liberopoulos *et al.*, 2003). We could only find the combination of variability in supply and unreliability in demand in papers by Hu *et al.* (2003, 2004) and by Toktay and Wein (2001). Here, however, the researchers only studied a single product situation.

The main aim of our research is to evaluate the effectiveness of safety stock and safety lead-time in coping with supply uncertainty in combination with three different types of demand uncertainty that we saw in our case study: uncertainty arising from changes in order size, uncertainties arising from changes in order type and uncertainties arising from changes in order sequence. The effectiveness of safety stock and safety lead-time has not been reported in the MRP literature in relation to changes in order type or sequence. In the ADI literature, a few papers have considered a combination of unreliable ADI and variable supply, but these papers have focused on a single product. Building on case study findings, we investigate the dilemma facing a planner as to whether to use safety stock or safety lead-time in a multiple product situation while taking several real life types of uncertainty into account.

5.3 Case description

The previous section shows that investigating further the use of safety stocks and safety lead-time in real life situations with multiple sources of uncertainty is a potentially promising direction for further research. Pursuing this goal, our study is firmly grounded in, and motivated by, a case study in a can factory delivering to a packaging firm in the food processing industry. The case study helped to explore the types and scales of the uncertainties faced in real life. These uncertainties and other uncovered system characteristics are used in the design of the simulation study, as described in the next section. To obtain the required information, interviews were held with shop floor managers and production planners. Additionally, procedures, planning data and data derived from the MRP

system were also studied. The interviews revealed that both supply variability and demand uncertainty have a major influence on the need for safety stock or a safety lead-time.

The studied can factory (see Figure 5.1) has five production lines that produce different types and sizes of cans. Cans are supplied to a packaging firm, where they are filled with condensed milk and subsequently packed into cardboard boxes. The can factory and the packaging firm are tightly coupled in the sense that there is limited intermediate storage capacity relative to the production speed: the maximum stock equates to two days of production. The production lines face regular breakdowns, reducing overall running times by about 20%. Production output is further influenced by the type and size of can, as well as by the set-ups involved.

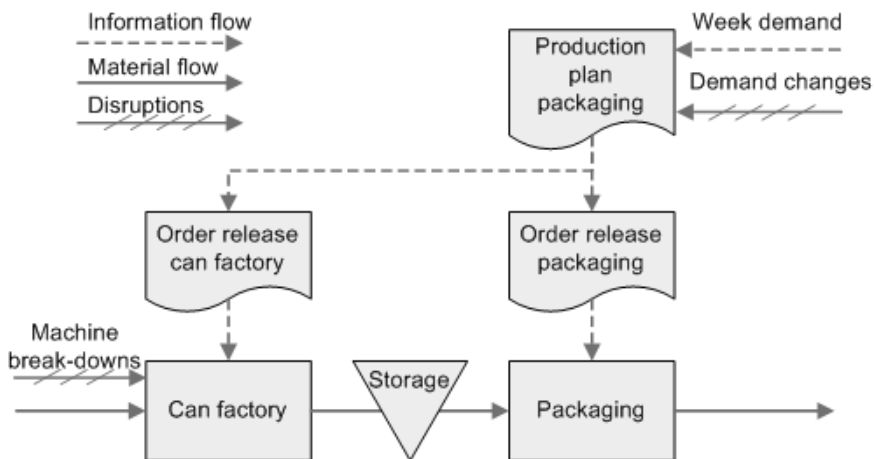


Figure 5.1: Dairy supply chain - Can factory and packaging firm.

Operations at the can factory and at the packaging firm are aligned through a single, weekly, production plan. The production plan provided by the packaging firm (which is considered as demand information for the can factory) may be adapted during execution. Plan changes are linked to customer order changes, the availability of raw materials and/or the availability of packaging materials. An analysis of production plans for one product size, over a period of 26 weeks, showed that the production plan was modified 82 times (average 3.2 modifications, range 1-8 modifications, per week). Each modification may involve multiple changes to the schedule, to which the can factory has to respond. Over a year, the utilisation of the different production lines in the can factory varied between 56 and 86 per cent.

Based on the case study, we concluded that the level of unreliability in both ADI and production output forces the use of safety stocks or safety

lead-times in order to guarantee acceptable delivery performance. The choice for, and the amount of, each option is based on the requested delivery performance. The options are restricted by the limited intermediate storage space, and influenced by efficiency considerations with respect to inventory, production and handling costs. Finding a suitable trade-off between restrictions and ambitions is one of the main tasks for the planners; with safety lead-time providing more flexibility and safety stock more responsiveness. For the planners it is not clear under what circumstances they should opt for safety stock and when for a safety lead-time. The subsequent simulation study helps the planners to choose the right type of buffer for different levels and types of unreliability in both demand information and production outcomes.

5.4 Design of the simulation study

Based on the question raised by the case study, namely which buffer measure to use under what circumstances, a simulation study was designed to investigate the effect of different levels of safety stock and safety lead-time on the ability to cope with uncertainties in demand and supply. In answering our main research question we evaluated the effectiveness of safety stock and safety lead-time in coping, in turn, with (1) supply variability, (2) various types of unreliability in demand information and (3) the combined effect of unreliability in demand information and supply variability. We measure the effectiveness of safety lead-time and safety stock on two dimensions: delivery performance and inventory level in the system.

The main variables in our simulation, largely determined from the case study, are summarised in Tables 5.1 and 5.2. For all experiments, product supply is modelled as a single machine processing multiple product types (equal product mix), where a change of product type requires a new set-up (assumed to take two hours). The availability of the machine is modelled as 80 per cent due to machine breakdowns. We chose to characterize the mean time to repair by a negative exponential distribution. This choice is motivated by a graphical analysis of company data on machine breakdowns – which lacked the precision for a more profound testing on the fit of the distribution. Furthermore, it is in line with related literature, see, for example Das (2008), Kuhn (1997), and Sulliman (2000). In a similar way we decided to represent the time to failure by a negative exponential distribution. Again the choice is confirmed in earlier research, see, for example, Das (2008), Kuhn (1997), Moinszadeh and Aggarwal (1997), and Sulliman (2000). In the model the mean time to repair represents supply variability (see Table 5.2). The mean time to failure is derived from the 80

per cent machine availability and the mean time to repair. The initial planned weekly workload of the production machine is constant on 228 units (one unit equates to 6 pallets of cans); however the demand changes during the period with respect to the type, the quantity and the sequence of products contained in the initial schedule. The modelled average supply lead-time of one unit is 32 minutes, and 228 units are produced weekly when the utilisation rate is 80 per cent. Based on the modelled workload of the system (228 units per week), individual orders from the packaging firm to the can factory are generated (uniform order size 10-50 units based on case data). These orders are not pre-empted, and are delivered in the demanded sequence.

Table 5.1 - The values of the fixed factors

Fixed factors	Value
Product mix	Equal
Machine setup time	2 hours
Average supply availability	0.80
Initial load of the system	228 units (approx. 80%)
Average unit supply lead-time	32 minutes
Order size	Uniform between 10 and 50
Duration of a period	7 days
New schedule generation time	3 days ahead of new period
Plan evaluation interval	12 hours
Order size change	Uniform within ± 20 .

Operations in the can factory follow the weekly (seven-day) production plan of the packaging firm including any changes they request. No uncertainties are foreseen in the modelled lead-times of the packaging firm. The production plan in the model is generated three days ahead of the start of the new week, and the production orders in the can factory are released based on this plan. The order release time to the machine depends on the planned due date, the machine set-up time, the supply lead-time of one unit, and the safety lead-time. Once an order in the can factory is finished, the next order is released until all the orders for one period are processed. The production plan may be adapted every 12 hours (the plan evaluation interval) depending on the experimental settings (see Table 5.2). If modifications in the orders from the packaging firm to the can factory occur, only orders which are known in the production plan but which are not yet started in the packaging firm can be changed. If the demand for an order that has already been released to the can factory increases, a rush order is generated. The basic control rule in the system is that orders are processed in the demanded sequence from the packaging firm unless there is a rush order.

Safety stock or safety lead-time

To answer the research question, six series of experiments are carried out (see Table 5.2). These experiments evaluate safety lead-time (ST) and safety stock (SS) on delivery performance and inventory level in alternative settings of uncertainty in demand and supply. Three related pairs of safety stock and safety lead-time levels are compared where eight hours of safety lead-time is the equivalent of 15 units' production time, assuming no additional set-ups are required. Therefore, in the five product scenarios the use of three units of safety stock of each product type are comparable to the use of 8 hours of safety lead-time.

Table 5.2 - The factors considered in the series of experiments

	Supply variability	Demand uncertainty			Safety lead-time	Safety stock	Number of SKUs
		Type change	Quantity change	Sequence change			
Series I	0; ½; 1; 1½; 2 hours				8; 16; 24 hours	3; 6; 9 units	5
Series II		0; 0.1; 0.2; 0.3; 0.4			8; 16; 24 hours	3; 6; 9 units	5
Series III			0; 0.1; 0.2; 0.3; 0.4		8; 16; 24 hours	3; 6; 9 units	5
Series IV				0; 0.1; 0.2; 0.3; 0.4	8; 16; 24 hours	3; 6; 9 units	5
Series V	1 hour *	0; 0.1; 0.2; 0.3; 0.4	0; 0.1; 0.2; 0.3; 0.4**	0; 0.1; 0.2; 0.3; 0.4**	8; 16; 24 hours	3; 6; 9 units	5
Series VI	1 hour *	0; 0.1; 0.2; 0.3; 0.4	0; 0.1; 0.2; 0.3; 0.4**	0; 0.1; 0.2; 0.3; 0.4**	16 hours	Equivalent to 16 hours***	1; 3; 5; 10

* For presentation reasons we fixed the level of supply variability to 1 hour. Additional experiments show comparable patterns for other levels of supply uncertainty (0:30h, 1:30h and 2:00h).

** Same level as type change uncertainty (i.e. chance 0.1 is evaluated when type change 0.1 is evaluated)

*** The level of safety stock of each unit depends on the number the SKUs; levels equivalent to 16 hours of safety lead-time were chosen.

In the first series of experiments, the effect of utilising safety lead-time and safety stock on delivery performance is studied in a situation where the supply is variable. A zero in Column 2 in Table 5.2 represents a constant supply, and other values represent increasing levels of variability. Supply breakdowns are modelled using a negative exponential function with the chosen supply variability (the mean time to repair) as its mean.

In the second to the fourth series of experiments, the effect of safety lead-time and safety stock on the delivery performance with unreliable ADI, in the form of product type changes, quantity changes and sequence changes are studied. These demand changes are modelled as the likelihood that a product plan change will be required at a plan evaluation moment where 0.1 represents a chance of 10%. The plan evaluation moment is set to 12 hours to approximate current practice for the company, which suggests that plans were changed up to two times a day. Changes in product type (series II) are modelled by randomly picking an order within the plan of which the demanded product type is modified, randomly picking from all product types with equal chance. Quantity changes (series III) are modelled as an order of which the production volume is modified. Based on the

empirical analysis of the order changes we restrict the order quantity changes to at most ± 20 units (uniform distribution), where we kept the modified order within the regular order size band (10 – 50 units). If an order change would violate these limits, the order quantity is set equal to the lower or the upper bound. Sequence changes (series IV) are modelled as two randomly selected orders whose positions in the production plan are switched.

In the fifth and the sixth series of experiments, the effects of safety lead-time and safety stock on delivery performance with a combination of the different ADI unreliabilities *and* supply variability are studied. In these series, only one level of the various demand changes is evaluated at the same time (i.e. all demand uncertainties have a probability of 0.1). Series V shows the effects of the various combinations of the different ADI unreliabilities and supply variability on the desirable levels of safety lead-time and safety stock. Experiment VI is added because we expect the number of stock keeping units (SKUs) to have a major influence on the effectiveness of safety lead-time and safety stock.

The series of experimental outcomes are evaluated in terms of delivery performance and inventory levels. Delivery performance is measured as the fraction of orders that meet the packaging due date according to the production plan. Inventory levels are measured since there is a strong focus on cost reductions in the case company and because their physical storage capacity is limited. Inventory levels are measured every 24 hours, revealing differences in the average level of inventory when adopting safety stock or safety lead-time approaches.

The software package that is used to carry out the simulation experiments is Tecnomatix Plant Simulation 7.6™. A total of 100 runs were carried out for each experiment. The system can be described as a non-terminating production system (operations run 24 hours a day - seven days a week). Therefore a warm up period was used to arrive at the steady state. The length of the warm-up period is determined using the Welch procedure (Law and Kelton, 2000) based on the observations of the can throughput times. Given the outcomes of the procedure, the warm-up period and run length are set at 150 and 1500 days respectively.

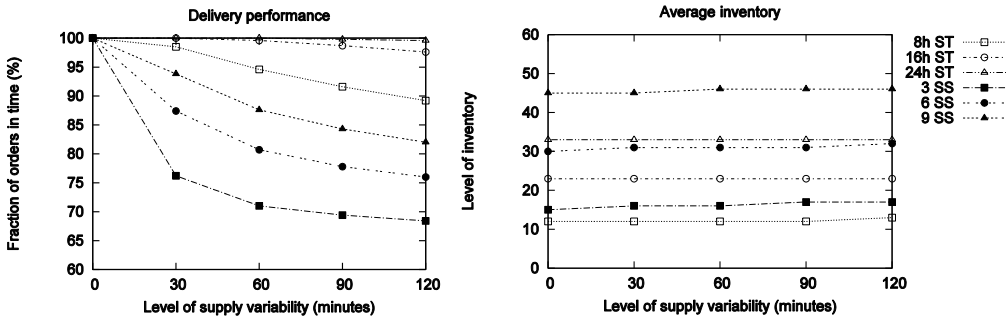
5.5 Results

In this section, we present the results for each series of experiments in the form of two figures: one showing delivery performance, and one depicting inventory levels. For all the experiments we found that the confidence interval half width is at most 0.8% for the delivery performance and 2.1% for the inventory levels respectively, given $\alpha=0.05$. Differences between

stock policies have been tested for statistical validity using a paired-t approach with a 95% confidence interval (see Law and Kelton, 2000). The tests pointed out that differences greater than 0.3% for delivery performance and 2.1% for inventory levels should be considered significant.

5.5.1 Comparing safety stock and safety lead-time with various levels of supply variability (Series I)

Figure 5.2 shows that greater supply variability leads to lower delivery performance. Safety lead-times lead to better delivery performance than equivalent levels of safety stock. As one adds more and more safety stock, or increases safety lead-time, the benefit diminishes. Figure 5.3 shows that utilising a safety lead-time results in lower inventory levels than holding equivalent levels of safety stocks. Increasing supply variability leads to a linear increase in inventory level but at a slow rate.

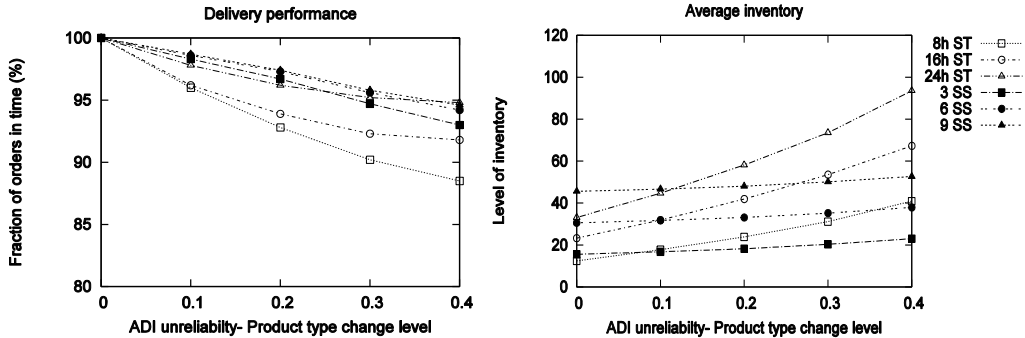


Figures 5.2 and 5.3: Delivery performance and average inventory levels for various amounts of safety stock and safety lead-time at different levels of supply uncertainty.

5.5.2 Comparing safety stock and safety lead-time in the event of product type changes (Series II)

Figure 5.4 shows that increasing unreliability in required product type leads to decreased delivery performance. Increases in safety lead-time or safety stock reduce the effect of ADI unreliability in product type on delivery. The differences in delivery performance for the various safety stock levels are small compared to those for the equivalent range of safety lead-times. In general, safety stock is more effective in managing this uncertainty, where only 24 units of ST achieves a comparable result to 9 units of SS at the highest level of uncertainty (0.4). Figure 5.5 shows that

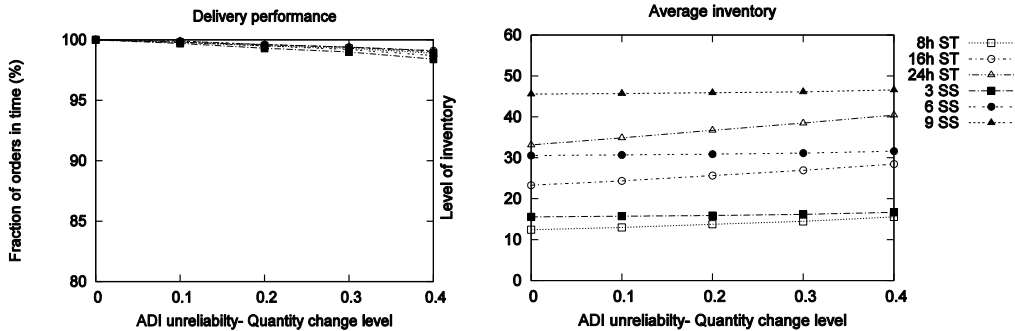
average inventory rises when unreliability in terms of product type increases. The effect of increasing ADI unreliability on the average inventory is greatest when pursuing a safety lead-time solution. A safety lead-time approach results in lower inventory levels when product type uncertainty is low, whereas a safety stock approach results in lower inventory levels when product type uncertainty is high.



Figures 5.4 and 5.5: Delivery performance and inventory levels for various amounts of safety stock and safety lead-time at different levels of product type changes.

5.5.3 Comparing safety stock and safety lead-time in the event of quantity changes (Series III)

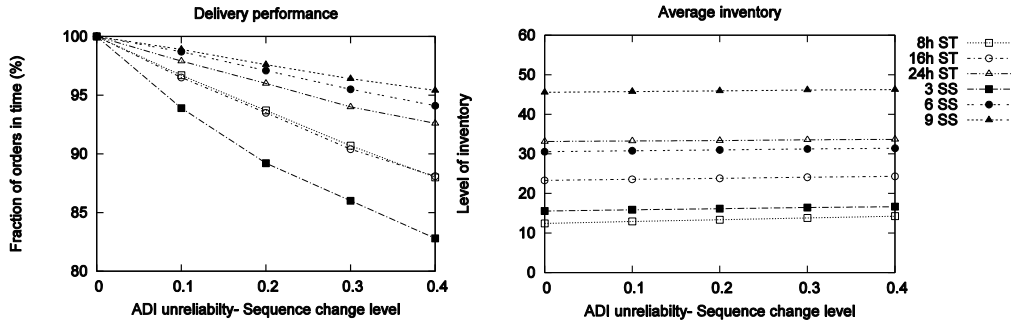
Figure 5.6 shows rather small differences (the scale is the same in all the figures reflecting ADI unreliabilities) in delivery performance between safety stock and safety lead-time approaches in the event of quantity changes compared to the differences seen for the other ADI uncertainties (as shown in Figures 5.4 and 5.8). In both approaches even high levels of quantity uncertainty have little impact on the delivery performance. Figure 5.7 shows that inventory levels rise if the uncertainty in demanded quantities increases. The increase is more marked when adopting a safety lead-time approach. Nevertheless, adopting a safety lead-time results in lower average inventory levels than if one had opted for an equivalent level of safety stock, even at high levels of quantity uncertainty.



Figures 5.6 and 5.7: Delivery performance and inventory levels for various amounts of safety stock and safety lead-time at different levels of quantity changes.

5.5.4 Comparing safety stock and safety lead-time in the event of sequence changes (Series IV)

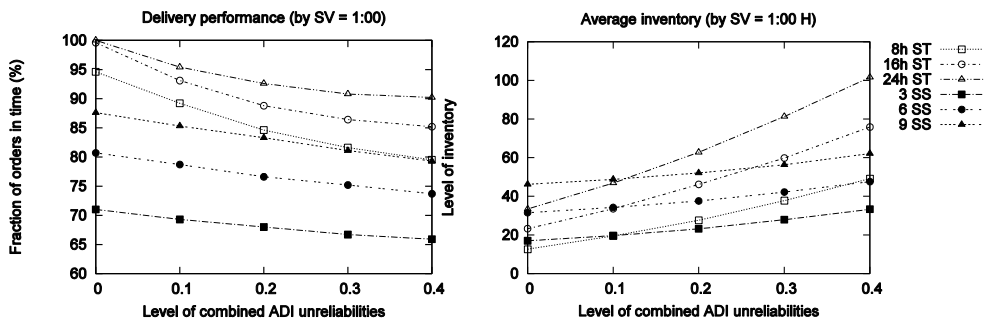
Figure 5.8 shows that increasing uncertainty in product sequencing reduces delivery performance, and that holding more safety stocks improves delivery performance in such a situation. The use of safety stocks results in a better delivery performance than if one had opted for safety lead-times with moderate or high safety settings (SS6 vs. ST16, SS9 vs. ST24), but lower delivery performance for low safety settings (SS3 vs. ST8). A large increase in delivery performance can be observed when going from SS3 to SS6 that can be related to the set-up time. With the values used in the simulation, the set-up period of two hours can be effectively buffered by a safety stock level of four or more units (four units is equivalent to 4 x 32 minutes of production time). A safety stock level of three units (SS3) cannot buffer an additional set-up, should one be required to adapt to a last-minute change in order sequence. Clearly, the larger simulated stocks (SS6 and SS9) can buffer such a loss of production time. Figure 5.8 further shows that the gain in delivery performance when going from 8ST to 16ST is small compared to the difference when further extending lead-time from 16ST to 24ST. This effect is discussed in Section 5.6.2. Figure 5.9 shows that inventory levels slightly rise when ADI unreliability increases, and that safety lead-times result in lower average inventory levels than equivalent levels of safety stock.



Figures 5.8 and 5.9: Delivery performance and inventory levels for various amounts of safety stock and safety lead-time at different levels of sequence changes.

5.5.5 Comparing safety stock and safety lead-time in the event of a combination of supply variability and different ADI unreliabilities (Series V)

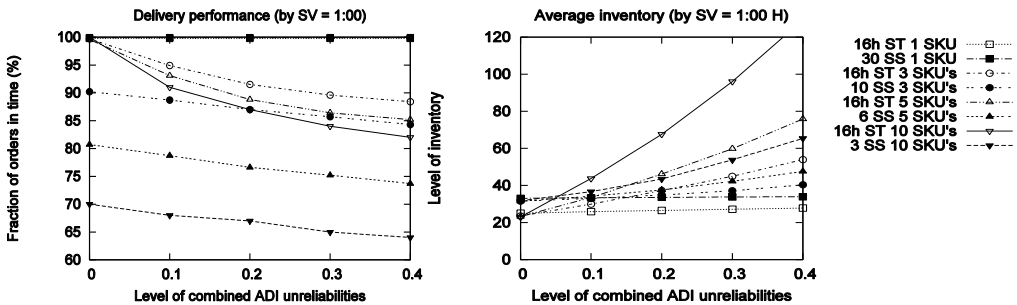
Figure 5.10 shows that increasing demand uncertainty reduces delivery performance, while increasing safety stock or safety lead-time improves delivery performance. The decrease in delivery performance as demand uncertainty increases is greater if one opts for a safety lead-time approach. Nevertheless, the use of a safety lead-time results, in all the situations considered, in a better delivery performance. Figure 5.11 shows that average inventory levels increase when the ADI unreliability increases. The inventory increase is larger if one opts for safety lead-times rather than equivalent safety stocks. Figure 5.11 shows a crossover point in inventory levels for comparable levels of safety lead-time and safety stock around an unreliability level of 0.1. Beyond this point, safety stocks result in lower average inventory levels than safety lead-times.



Figures 5.10 and 5.11: Delivery performance and inventory levels for various amounts of safety stock and safety lead-time at different combinations of ADI unreliability and a constant level of supply variability.

5.5.6 Comparing safety stock and safety lead-time in the event of a combination of supply variability and various sources of ADI unreliability with different quantities of SKUs (Series VI)

Figure 5.12 shows that a single product situation results in identical delivery performances for safety stock and safety lead-time approaches. In a multiple product situation (3, 5, 10 SKUs), delivery performance is better when following a safety lead-time approach than when holding a comparable level of safety stock. The difference in delivery performance, between safety lead-time and safety stocks, increases as the number of SKUs increases. Figure 5.12 further shows that delivery performance worsens as the level of demand uncertainty increases. The decrease in performance is larger if a safety lead-time approach is pursued. Figure 5.13 shows that the average inventory level, in a single product situation, is lower if a safety lead-time approach is applied whereas, in general, in multiple product situations, inventory levels are lower if a safety stock policy is adopted. In multiple product situations, safety lead-times only result in lower inventory levels at low levels of ADI unreliability. In multiple product environments, the crossover point for average inventory levels, given comparable levels of safety stock and safety lead-time, depends on the number of SKUs. Increasing the number of SKUs will shift the crossover point to lower levels of uncertainty, leading to higher average inventory levels when a safety lead-time approach is used compared to a safety stock approach.



Figures 5.12 and 5.13: Delivery performance and inventory levels for various amounts of safety stock and safety lead-time with different combinations of ADI unreliability, a constant level of supply variability and various numbers of SKUs.

5.5.7 The effect on inventory space

The inventory graphs in Section 5.5.1-5.5.6 show the average inventory, which is an important measure to determine differences in inventory holding cost between safety stock and safety lead-time. However, space needs is also of interest as it limits the inventory level. Therefore the 95 percentile of the inventory level measurements is studied, as a measure for the space needs. Studying this point revealed that the storage space needs for safety stock or safety lead-time in the series of experiments are 12 to 93 per cent higher than the average inventory level (see Table 5.3). Specifically for series II, V, and VI we find high inventory space requirements, suggesting that for realistic settings of inventory space, extra care has to be taken in transferring the average inventory results into space requirements. In general, high inventory level fluctuations (as in series II, V, VI, related to respectively type change, multiple uncertainties and multiple uncertainties) can be associated with rapid increases in average inventory levels when the uncertainty levels increase (see the inventory graphs in Section 5.5.1-5.5.6).

Table 5.3. Differences between the mean and the 95-percentile storage needs.

	Safety stock			Safety lead-time		
	Mean	95 percentile	% difference	Mean	95 percentile	% difference
Series I	31,5	41,1	31%	23,1	38,4	66%
Series II	33,7	52,4	56%	43,1	82,4	91%
Series III	31,0	34,6	12%	25,4	40,1	57%
Series IV	31,0	35,0	13%	23,5	34,9	48%
Series V	38,6	67,1	74%	47,4	91,6	93%
Series VI	38,4	63,8	66%	46,0	86,4	88%

5.6 Discussion

This section is organised in line with the three research issues concerning respectively: the effect of supply variability, the effect of demand uncertainty, and their combined effect.

5.6.1 The effect of supply variability

The first research issue concerns determining the effect of supply variability. Experiment series I found that increasing levels of supply variability decreases delivery performance. The literature reports similar relationships (e.g. Karaesmen, 2003; Kunnumkal and Topaloglu, 2008). Incorporating a safety lead-time is found to lead to better delivery performance than holding a safety stock when coping with supply

variability (see Figure 5.2). This can be explained by the inherent mix flexibility associated with a safety lead-time, since products are not pre-specified as they are with safety stocks.

Utilising a safety lead-time achieves a better delivery performance while resulting in lower average inventory levels (see Figure 5.3). With a safety lead-time, inventory levels decrease in advance of a period without any demand (e.g. at the end of a production period or during a machine set-up) and this results in lower average inventory levels than if a safety stock approach is used. The benefits decrease as the system becomes more loaded.

5.6.2 The effect of demand uncertainty

The second research issue concerned the effect of uncertainty in demand. Experiment series II to IV show that increases in ADI unreliability (in three different forms) decreases delivery performance. This outcome is again in line with earlier findings (e.g. Bourland *et al.*, 1996; Tan *et al.*, 2007). In general, holding a safety stock is found to be more effective than buffering in a safety lead-time in coping with ADI unreliability. The greater effectiveness of safety stock can be explained by the consequent ability to have tighter coupling between the supplying company and demanding company. Orders to the supplying company can be released later than in a similar situation relying on a safety lead-time, and this makes the system less vulnerable to demand changes. While Liberopoulos *et al.* (2003) found that safety stock and safety lead-time are totally interchangeable in a single product situation, we find that holding a safety stock is more effective in a multiple product setting.

The various types of demand uncertainty affect delivery performance differently. This can be observed in Figures 5.4, 5.6 and 5.8, where the effect of a change in order quantity is relatively small compared to the effect of changing either the product type or the production sequence. The difference can be explained by the magnitude of the change and the set-up implications. Firstly, if a quantity is changed, the magnitude of that change is limited since an order is modified (we used a uniform distribution of ± 20 units, see Table 5.1) compared to a product type or a sequence change where an entire order is changed (a uniform distribution from 10 to 50, see Table 5.1 order size). Secondly, quantity changes result in fewer set-up changeovers than product type or sequence changes.

The chosen level of safety stock for each product type should be sufficient to cope with at least one additional set-up. In Figure 5.8, this is illustrated by the large gain in performance by increasing the safety stock from three to six units.

The length of a safety lead-time needs to be chosen with caution. Extending safety lead-time, on the one hand, increases the likelihood that changes in the production plan can be accommodated but, on the other hand, it also increases the likelihood that production is already under way when an order modification is received. The effect is illustrated in Figure 5.8 where safety lead-times of 8 hours and 16 hours result in similar delivery performances. Further experimental runs with a wider range of safety lead-times reveal that the marginal effect of additional safety lead-time decreases the delivery performance up to around 10 hours of safety lead-time (the specific point depending on the model parameters investigated), when it starts to increase again. This results in nearly the same delivery performance with both 8 hours and 16 hours supply lead-time. Figure 5.4 also shows this effect: 8 hour and 16 hour safety lead-times result in comparable delivery performances at the 0 and 0.1 demand uncertainty levels.

In the event of demand uncertainties, a safety lead-time results in lower average inventory levels at low levels of uncertainty but, at higher uncertainty levels, the required inventory levels increase more rapidly with the safety lead-time option (see Figures 5.5, 5.7 and 5.9). The difference between the two options at low levels of uncertainty can be explained by the workload of the system as explained above in Section 5.6.1. The difference in the rate of inventory growth as uncertainties increase can be explained by the fact that, using safety stocks, orders to the supplying company are released later. This reduces the likelihood that the supplying company has already started producing a wrong type of product.

The various types of demand uncertainty differently influence the average inventory levels. Figures 5.5, 5.7 and 5.9 show that changes to product type have the greatest impact on average inventory levels. This can be explained, firstly, by the limited magnitude of allowed quantity changes (see Section 5.6.1) and, secondly, by the fact that all production will still be used within the same production period in the event of a sequence change. In comparison, there is greater uncertainty attached to a type change.

5.6.3 The combination of supply and demand uncertainty

The third research issue concerns the combined effect of demand uncertainty and supply variability. Experiment series V and VI show that increasing levels of ADI unreliability combined with supply variability decreases delivery performance. Within the investigated combinations of variable supply and ADI uncertainty, it is more effective (i.e. better delivery performance) to use safety lead-time rather than safety stock in a multiple product situation.

Safety lead-time and safety stock achieve almost identical performances when there is only one SKU. This finding is in line with those of Liberopoulos *et al.* (2003) who showed that safety stock and safety lead-time are interchangeable when only demand variability is considered in a single product situation. Increasing the number of SKUs decreases delivery performance. The fall off performance is lower when the safety lead-time approach is selected because this approach provides some mix flexibility whereas a safety stock does not.

Higher levels of ADI unreliability have a greater impact on the delivery performance when the safety lead-time approach is selected. This can be explained by the fact that safety lead-time is more sensitive to ADI changes than safety stock (comparable to series II to IV) and the fact that the delivery performance with zero demand uncertainty is already lower with the safety stock option (due to the supply variability) which reduces the effect of additional disturbances.

The results further show that inventory levels more rapidly increase when adopting a safety lead-time approach as the level of uncertainty or the number of SKUs increases. The rapid increase can be explained by the greater likelihood that the wrong product is produced, combined with the reduced likelihood that the excess stock will be quickly required when there are many different SKUs.

5.7 Conclusions and future research

Motivated by the industrial case study in the food processing industry, this paper studies the advantages and disadvantages of either safety stock or safety lead-time in a multiple product system with a variable supply and unreliability in demand information. The benefit of safety stock is its responsiveness, whereas safety lead-time increases flexibility. What was not clear was which buffer strategy is the more effective under specific circumstances.

This study shows that a safety lead-time is the more effective strategy for coping with supply variability. Conversely, in most cases, holding a safety stock is to be preferred in coping with uncertainties in demand information. For situations with uncertainties in both supply and demand information, a safety lead-time is more effective than an equivalent level of safety stock. The downside of adopting a safety lead-time is that it leads to higher inventory levels and to a higher spread in inventory storage needs than with a comparable level of safety stock when demand uncertainty is high. These differences in delivery performance and inventory levels between the use of safety stock and safety lead-time become more significant as the number of SKUs increases.

This study has answered some of the questions concerning the use of safety stock and safety lead-time in a multiple product situation, but it is also limited by its design. The design of the simulation study is based on a single case study. Although our situation contributes to an integrated approach, including multiple types of uncertainties and realistic parameter settings, modelling other industrial settings will certainly require the addition of other factors such as the pre-emptiveness of jobs, other types of uncertainties, other demand and supply distributions or other dependencies in planning and production. Nevertheless, our study is relevant for a wider audience, as it addresses general types of uncertainty with respect to supply variability, type change, and order size and sequence change. We believe that achieving the optimum trade-off between safety lead-time and safety stock is a generic and pervasive problem in many industries and supply chains.

Practitioners can benefit from our findings. Specifically, we would advise planners in high volume processing/packaging industries who are faced with a combination of supply variability and uncertainties in demand information to opt for a safety lead-time approach since this is the more effective. The optimum extent of the safety lead-time will depend on the available storage capacity and storage costs. Further, we found that the effects of the various types of demand uncertainty on delivery performance differ, with product type and sequence changes having a greater impact than quantity changes. Therefore, if a planner can influence the kind of demand uncertainty to be faced, delivery performance could be increased. By creating a situation in which demand uncertainty linked to product type is reduced, inventory levels could be cut since changes to product type have a greater impact on inventory levels than production sequence changes or order quantity changes. Our study confirms the experiences of the managers in our case-company with respect to the advantages (higher delivery performance) and disadvantages (high inventories when demand uncertainty is high) of the use of safety lead-time to deal with a situation of uncertainty in supply and demand. Their experiences and our results made them decide to test the benefits of a combined approach in partly shifting to safety stock in circumstances where there is advance information concerning potential production schedule changes to mitigate the negative inventory level effects of safety lead-time.

Several promising directions for further research remain. In future research one could study combined safety stock and safety lead-time policies taking advance information concerning potential production schedule changes into account, like the flexible policy suggested in the previous paragraph. Another direction for further research is to relax specific case study based constraints that we used as this may extend the

applicability of the findings. For example, other real life situations might involve different uncertainties, or situations in which rush orders might lead to the halting of an order in progress, which could be modelled as a pre-emption. Another direction for further research relates to the effect of additional safety lead-time in a situation with demand uncertainty. This subject was raised in our discussion in Section 5.6.2 where Figures 5.4 and 5.8 revealed that the effect on delivery performance of additional safety lead-time is not always positive. Finally, another direction for future research is to relate the delivery performance changes of changing the amount of safety lead-time or safety stocks to the associated changes in inventory holding costs. This would explicitly address the trade-off between delivery performance and storage costs and show in which situations additional buffering measures should be taken. Based on the economic benefits of improved delivery performance and the costs of storing more products, one could decide on the appropriate inventory level.

6. Conclusions

Food processing companies experience growing logistical demands as product variety and uncertainty are increasing while competition becomes more intense. As a result, companies reconsider the way the production processes are planned and controlled. However, the reconsideration is complicated as the food processing industry has a number of typical characteristics that need to be considered in planning. Answers have to be found how production sites can deal with the typical food characteristics while higher logistical demands have to be met.

The present thesis reports on planning in the food processing industry. The main research objective is to understand how industry specific characteristics affect planning in the food processing industry. As a starting point, the introduction of the thesis summarizes the typical food characteristics and the recent research in the area. Moreover, it shows practical challenges which food processing companies face on different planning levels. The thesis consists of studies on planning in the context of a dairy company. Decisions on production strategy, buffering policies and postponement options are related to the specific characteristics of the food processing industry by which we contribute to the main research objective of the thesis. In this final chapter we discuss and reflect upon the main findings of the chapters and the related implications for theory and practice. Moreover, we discuss how we balanced scientific and managerial needs in the project and reflect upon how future projects can benefit from our experiences. Finally, directions for further research and reflections on the societal relevance of the project are provided.

6.1 Main findings

Chapter 2 contributes to the literature by providing a structured model on Stock Keeping Unit (SKU) classification based on a systematic analysis of the literature. The chapter results in an overview of aims, techniques and characteristics used to classify SKUs in various contexts. The main finding in Chapter 2 is that a classification depends on the aim, the context, and the method that is chosen. Chapter 2 discusses how these aspects relate to each other and which decisions have to be made on these aspects in order to come to a SKU classification. The conceptual framework and the discussion underpinning the framework provide the groundwork for theory building with respect to SKU classification. Further studies can refine the framework by, for example, unravelling whether deeper logic can be found to explain

how the different SKU classification decisions are made or should be made. The main managerial implication of this chapter is that determining a classification should not be done on managerial insight only. The chapter provides an extensive list of examples from a variety of industries, which is combined with classification guidelines. These examples and guidelines can aid managers in developing their own SKU classifications.

Chapter 3 contributes to the literature by providing insight in how SKUs are classified and reclassified into production strategies in the dairy industry. A main finding of the chapter is that typical food processing characteristics (perishability, variability in demand, minimal batch sizes and cyclical production plans) affect the production strategy classification. Moreover, the chapter stresses the need to adapt a classification over time and provides a number of reasons why the classification and reclassification process is more subtle than just a straightforward calculation. A research implication of this study is that payment reliability, which was not found in the structured review, is a relevant factor when shipping food products to unreliable markets. A second research implication of the study is that classifications of SKUs should not be seen as more or less fixed but should be updated due to varying market conditions. Therefore more attention should be paid to the dynamic nature of the characteristics on which a classification is based. Finally, we found that customer requests have a great impact on a classification. If customers accept the risk of stocks becoming obsolete than the favourable Make-to-stock (MTS) policy is in reach for SKUs that normally would be classified as Make-to-order (MTO). The main managerial implications of this chapter are that it provides an example which characteristics are included in a food processing company, it shows the relevant factors that affect the revision of classification over time (e.g. changed demand volumes, changed forecast accuracy) and it shows factors that hinder the reclassification (e.g. customer wishes, workload to adapt the classification). Managers that have read the chapter are stimulated to guarantee in their organisation that a SKU is reclassified periodically by, for example, defining an interval for updating the classification.

Chapter 4 contributes to theory by providing insight how food processing industry characteristics affect the operational performance of implementing form postponement (FP). A main finding of the chapter is that we confirm that applying FP has high performance gains in production settings with a high product variety and high demand uncertainty. Additionally, we found that two specific food process industry characteristics, that usually limit flexibility, might be mitigated by implementing FP. Firstly, implementing FP can relax restrictions on minimal batch sizes and as such enable large

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reductions in inventory levels. Secondly, FP can relax the strictness of cyclical production plans, which can result in shorter production intervals and in turn reduced stock levels as well. The main theoretical implication of this study is that some typical food processing contingencies, which commonly restrict production planning, can be overcome by implementing FP. As such the order penetration point can be positioned further downstream. Therefore, FP should be reflected upon in production strategy considerations as it can enable the shift from MTS to MTO. The main managerial implication of the study is that it shows that planning limitations in the processing phase can be overcome by implementing FP. As such the packaging phase can be planned more flexible, enabling companies to react faster to the changing customer demand.

Chapter 5 contributes to theory by providing insight in the advantages and disadvantages of either safety stock or safety lead-time as a buffer strategy between two departments. The main findings of the chapter are that a safety lead-time is a more effective strategy for coping with supply variability. Conversely, holding a safety stock is to be preferred in coping with uncertainties in demand. For situations with uncertainties in both supply and demand a safety lead-time is more effective than an equivalent level of safety stock. The main theoretical implication of this chapter is that different buffering strategies are preferred in different circumstances depending on the sources of uncertainty. However, if multiple types of uncertainty occur at the same time, safety lead-time results in a better delivery performance but at higher levels of inventory. The main managerial implication of the study is that it guides managers in the selection of the appropriate buffering strategy under different levels of uncertainties.

The contribution of the thesis as a whole is that it shows how food processing characteristics affect planning decisions from multiple perspectives. Chapters 3-5 respectively take the perspective of the customer (SKU classification), the company redesigning the production process (form postponement), and the internal supplier (buffering strategies). All the typical food processing characteristics, as discussed in Chapter 1, can be noticed in one or more of the different chapters (see Table 1.1 for an overview) and affect how planning decisions are made. By showing how these characteristics of the food processing industry affect planning decisions we stress the importance of tailoring planning approaches to the contextual settings in which they are used. Therewith the thesis contributes to a broader line of research at the University of

Groningen studying how planning is organized in the food processing industries.

6.2 Balancing practical and scientific relevance

While studying how typical food processing characteristics affect planning decisions in this thesis, we have the ambitions as sketched by Guide and Van Wassenhove (2007) to be both scientific and practical relevant. Given that operations management (OM) is a practical field (Meredith, 2001) we expected that by staying close to practice, synergy could be obtained while addressing the questions of both worlds. Nonetheless, after the four years the project lasted we agree with Guide and Van Wassenhove (2007) and Holmstrom *et al.* (2009) that synergy is possible but cannot be obtained easily as goals and research interests of practice and academia diverge. Managers are more focussed on problem-solving-oriented research where empirical OM research attempts to build explanatory theory. At some times during the project we therefore felt stuck in the middle between the managerial and theoretical interests. We dealt with the difference by freeing time to work on practical problems that provided us the trust and credit of the company to collect data that we needed to write our papers on the theoretical perspective. Moreover, working closely to practice also inspired the approach in the papers. Only focussing on the theoretical perspective would not have resulted in the same depth of insight in the planning practices and same access to the data that we have used in our papers. That the company was problem-driven sometimes led to puzzling situations. In a certain project a problem was perceived as highly urgent and the management stressed the relevance of studying this problem. However, a few months later the problem was no longer a major concern and therewith the management attention ceased. As a result it was not possible to continue studying the problem and we ended the project from an academic point of view as well.

In order to avoid being too dependent on changeable management interests while conducting practically relevant research we balanced the interests of practice and academia by discussing each three months the progress of the research in a steering committee with representatives from both the university and the company. This resulted in a broad bearing surface when projects were selected. However, as the example in the previous section illustrates, even this approach did not result in success only. Yet, we argue that proper project selection taking both the academic and the practical needs into account did increase the chance on project success. The steering committee selected projects based on both the theoretical and practical exploration of the topic. In most cases the next step

was to work on the practical problem for the specific situation. This resulted in practical insight for the company. A second step was to adapt the practical problem in such a way that it represents a broader applicable problem (for example, by removing or simplifying typical characteristics of the case company such as labour constraints, scheduling sequence preferences, number of SKUs). To increase the generalizability of our findings how to deal with a planning problem in the case company, we included a simulation study in two papers in which a wider range of variables was analysed. Our approach did not guarantee full synergy between the two different worlds, but the approach did result in cross-fertilization as the outcomes of theoretical models greatly inspired discussing the relevant factors in practice. At the same time these discussions in practice resulted in the inclusion or fine-tuning of characteristics that we used in the theoretical and/or simulation models. Moreover, working on the practical problem provided in-depth access to information and data in the case company.

The collaboration between the university and the case company in the project resulted in improved planning procedures in the case company where at the same time the scientific knowledge on planning in the food processing industries was enriched. The question remains what the factors of success were in this project. First of all we perceive that it is important to acknowledge and satisfy the different needs both parties have. Excessively emphasizing either the practical or the scientific side will not do the job. Periodically discussing the progress on both the scientific and the practical side in the steering committee was of great value. Another important aspect is that the researcher should be able to function in both the scientific and the practical world. Working with managers should not be seen as a burden but enjoyable and inspiring. This idea is supported by Guide and Van Wassenhove (2007).

6.3 Directions for further research

Opposing the best practice paradigm (Voss, 1995; Flynn *et al.* 1999), that assumes that the adoption of best (world class) practice in a wide range of areas leads to superior performance, this research project is based on the premise that the context matters in selecting the best planning solution (Whetten, 1989; Sousa and Voss, 2008). We show that typical characteristics of the food processing industry affect planning approaches. However, there might be other contingencies, next to industry, which could be relevant. Therefore, a direction for future research is to study to which extent our findings hold in other contextual settings. Table 1 in Sousa and Voss (2008) shows known contingency factors that affect best practices in

manufacturing operations (e.g. firm size). Based on the high presence of a number of factors in this list, we advise to include other industries, other firm sizes and other countries of location in future studies to understand to which extent our findings can be generalised.

The explorative aim of our research and the research possibilities provided by the dairy company made that we selected a single case study approach. In order to maximise the generalizability of a single case, we selected a case company that was typical for the food processing industry (the “typical case”, cf. Yin, 2003) and used simulation models to study similar production settings. A direction for future research is to stretch the generalizability by conducting a multiple case study how other food processing companies apply the planning approaches studied in Chapters 3-5. Multiple cases can be studied by either collaborating with a large company or by collaborating with an interest group, for example the Dutch Union for Logistics Management (VLM). When comparing different approaches of the production sites, we expect that differences can be found. Firstly, this could be based on different contingencies in which the companies operate. Identifying how these contingencies affect optimal planning procedures is a great way to improve scientific knowledge on planning procedures. A second reason for finding differences could be that companies are not aware or unable to implement the appropriate planning procedures. Van Wezel *et al.* (2006) identified a large gap between production management theory and organizational practice in small and medium sized companies. We expect that comparing multiple production settings and discussing the outcomes with the companies will result in a large number of practical improvements and food for thought to further improve the planning procedures currently in use.

6.4 Societal relevance

This research project was conducted in close collaboration with industry and directly affected the decisions making practice in the case company. The way the company determines the production strategy, buffering strategy, postponement decisions and optimal order quantities is improved through our collaboration. Moreover, the insight that is obtained on production processes and how to improve the planning of these processes can be used to increase the operational performance of other production plants within the company. Still, the societal benefits stretch further than optimizing planning in this single company. Given that the case company is a typical example of the food processing industry, the outcomes of this thesis can be used to improve the operational performance of other food processing companies as well. As a consequence, our study contributes to

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keeping the cost for processing food low. Therewith it supports companies in the Netherlands and Europe to stay competitive in globalizing food markets in which competition is increasing. In dairy this is essential, as patronage constructions of the EU will cease in 2015.

7. References

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8. Samenvatting (Summary in Dutch)

Dit proefschrift richt zich op planning in de voedselverwerkingsindustrie. Bedrijven in de voedselverwerkingsindustrie staan voor steeds complexere logistieke vraagstukken. De productvariëteit en vraagonzekerheid nemen toe terwijl de concurrentie intensiveert. Dit heeft tot gevolg dat bedrijven heroverwegen hoe productieprocessen gepland en beheerst moeten worden. Echter, in de voedselverwerkingsindustrie worden planningsoverwegingen gecompliceerd door een aantal kenmerkende karakteristieken van deze industrie. Voorbeelden hiervan zijn minimale batchgroottes (koffiemelk maken lukt bijvoorbeeld pas vanaf hoeveelheden van 15.000 liter) en houdbaarheid van de producten. De vraag is hoe bedrijven rekening kunnen houden met deze kenmerkende karakteristieken en tegelijkertijd kunnen voldoen aan de hogere logistieke eisen die de markt aan hen stelt.

Het belangrijkste doel van dit proefschrift is te begrijpen hoe karakteristieken die kenmerkend zijn voor de voedselverwerkingsindustrie invloed hebben op de manier van plannen. De samenwerking tussen de Rijksuniversiteit Groningen en FrieslandCampina gaf een unieke mogelijkheid om vanuit de praktijk planningsvraagstukken te onderzoeken. Daarom ligt de basis van de planningsvraagstukken die in de hoofdstukken worden beschreven in de praktijk. Hoofdstuk 1 gaat in op de kenmerkende karakteristieken van de voedselverwerkingsindustrie. Dit hoofdstuk inventariseert wat bekend is in de literatuur ten aanzien van de invloed van deze karakteristieken op planningsvraagstukken. Tevens wordt een koppeling gemaakt met planningsvraagstukken in de praktijk. Daarmee schetst hoofdstuk 1 de context voor de planningsvraagstukken die behandeld worden in hoofdstuk 2 tot en met 5.

Hoofdstuk 2 en 3 gaan in op het classificeren (het in groepen indelen) van producten. Hoofdstuk 2 start met een literatuuroverzicht waarin 45 classificatiepapers geanalyseerd worden. Dit hoofdstuk geeft een overzicht van de doelen, technieken en de karakteristieken die worden gebruikt in classificaties. Uit de bestaande factoren in literatuur is in hoofdstuk 2 een conceptueel model gedestilleerd voor het classificeren van producten. De belangrijkste bijdrage van dit hoofdstuk is dat het laat zien hoe classificatiedoelen, de context van een classificatie en de classificatiemethode zich tot elkaar verhouden en welke onderliggende keuzes gemaakt moeten worden om tot een classificatie te komen. Daarmee wordt classificeren minder afhankelijk van het inzicht van een individuele manager maar is er een raamwerk van richtlijnen. Dit raamwerk kan in de praktijk kunnen worden gebruikt en in de theorie verder worden

aangescherpt. Hoofdstuk 3 behandelt hoe, op basis van het raamwerk van hoofdstuk 2, de productiestrategie (bijvoorbeeld producten op order produceren of op voorraad produceren) in de zuivelindustrie kan worden bepaald. Een belangrijke uitkomst is dat kenmerkende karakteristieken van de voedselverwerkingsindustrie (houdbaarheid, schommelingen in de vraag, minimale batches en cyclische productieplannen) de keuze voor een productiestrategie beïnvloeden. Daarnaast illustreert dit hoofdstuk de noodzaak voor en de effecten van het bijstellen van een productiestrategie omdat de aspecten waarop de classificatie is gebaseerd in de loop van de tijd veranderen (o.a. vraagvolumes en betrouwbaarheid van de vraagvoorspelling). Een derde uitkomst is dat het hoofdstuk redenen aangeeft waarom de gebruikte classificatie in de praktijk afwijkt van de gestructureerde uitkomst van het classificatieproces.

Hoofdstuk 4 gaat in op Form Postponement (het uitstellen van het moment dat een product zijn definitieve vorm krijgt). Het hoofdstuk laat door middel van een case studie en een simulatiemodel zien op welke wijze karakteristieken in de procesindustrie de performance beïnvloeden van het invoeren van Form Postponement (FP). Het toepassen van FP leidt tot grote verbeteringen in de operationele performance vooral in situaties waar sprake is van een grote productvariatie én een hoge onzekerheid over welke producten worden gevraagd door de klant. Daarnaast laat het zien dat twee kenmerkende en belemmerende karakteristieken van de procesindustrie overwonnen kunnen worden door de invoering van FP. Allereerst kan het invoeren van FP er voor zorgen dat beperkingen op minimale productiehoeveelheden op individuele producten geen invloed meer hebben doordat volumes van meerdere producten tezamen kunnen worden geproduceerd. Daarmee kunnen productiehoeveelheden en voorraden worden verlaagd. Ten tweede blijkt dat de invoering van FP kan resulteren in een versoepeling van het cyclische productieplan. Deze versoepeling leidt tot kortere productie intervallen en daarmee tot lagere voorraden of tot kortere levertijden. De belangrijkste implicatie van dit hoofdstuk is dat het duidelijk maakt dat een aantal kenmerkende karakteristieken van de procesindustrie die de productie belemmeren overwonnen kunnen worden door de invoering van FP. Als gevolg van deze verandering kan ook de productiestrategie aangepast worden. Voor sommige producten wordt een MTO strategie mogelijk in plaats van een MTS strategie. Daarmee kunnen bedrijven sneller reageren op veranderingen in de vraag van de klant.

Hoofdstuk 5 gaat in op de keuze van een bufferstrategie. Het hoofdstuk behandelt de voordelen en nadelen van veiligheidsvoorraad (safety stock) of veiligheidsleidtijd (safety lead-time) als methode om te bufferen tussen twee afdelingen. In het geval van safety stock produceert de leverende afdeling in

lijn (direct) wat de andere afdeling vraagt, waarbij van een aantal producten een vaste voorraad aanwezig is om storingen op te vangen. Bij safety lead-time kiest de leverende afdeling ervoor om niet een vaste voorraad neer te leggen maar om een bepaalde tijd voor te lopen op de klantvraag (bijvoorbeeld op maandag worden de producten gemaakt die op dinsdag gevraagd worden). Hoofdstuk 5 maakt duidelijk dat safety lead-time de beste optie is in het geval van verstoringen in de productiemachines terwijl safety stock de voorkeur geniet in het geval van onzekerheid in de vraag (wijzigingen in het productieplan van de afnemende afdeling). In situaties waar verstoringen in de vraag én in de productie voorkomen is safety lead time effectiever dan safety stock. De belangrijkste bijdrage van dit hoofdstuk voor de praktijk is dat het inzicht geeft in het effect van verschillende bufferstrategieën en daarmee aan managers richting geeft in de keuze voor een bufferstrategie.

Hoofdstuk 6 geeft een samenvattende discussie over de theoretische en praktische implicaties van de uitkomsten van de voorgaande hoofdstukken. Hoofdstuk 6 geeft daarmee een overzicht hoe de kenmerkende karakteristieken van de voedselverwerkingsindustrie op de verschillende planningsniveaus invloed hebben op de planningskeuzes die worden gemaakt. Daarnaast reflecteert hoofdstuk 6 over hoe wetenschappelijke en praktijkbelangen afgewogen zijn tijdens dit project, geeft het richting voor verder onderzoek en reflecteert het op de implicaties van dit proefschrift voor de samenleving.

Doordat in 2015 de melkquota in Europa worden vrijgegeven, is de verwachting dat de melkverwerkingsindustrie een turbulente periode staat te wachten. In die turbulentie is het noodzakelijk om continu na te blijven denken over hoe deze melkstromen gepland en beheerst kunnen worden. Dit proefschrift over planning in de voedselverwerkingsindustrie levert daar een bijdrage aan.

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